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CONTRACTOR REPORT

TRANSIENT REACTIVE EXHAUST FLOW FROM

A RING-SYMMETRIC HF/DF SPACE LASER

by

Joseph Falcovitz

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ABSTRACT

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cross-section area (of diffuser or nozzle) A Avogadro's number 6.022×10^{26} (molecules/kmole) A_v sound speed $(m \text{ sec}^{-1})$ С total energy per unit volume (MJ m⁻³) E mole fraction of species X at diffuser entrance f_X rate of hydrogen recombination collisions (with HF or DF) per unit volume $(m^{-3} \text{ sec}^{-1})$ g_c hydrogen recombination rate constant $[(mole; cm^3)^{-2} sec^{-1}]$ k₀ modified hydrogen recombination rate constant $[(kg/m^3)^{-2} sec^{-1}]$ \mathbf{k}_{1} Mach number М number density (molecules/m³) n Ρ pressure (Pa) formation energy of **H**₂ (KJ/mole) Q_H hydrogen recombination energy release parameter (MJ/kg) Q_{DET} time (ms) t Т temperature (K) U flow velocity (m/sec) average molecular weight (kg/kmole) W radial coordinate (in diffuser) x normalized mole fraction of H (Z = 1 at diffuser entrance)Ζ turning angle of flow velocity in a corner expansion to vacuum U turning angle increment for transient corner expansion $\Delta \alpha$ specific-heat ratio γ density (kg m⁻³) ρ inclination of flow velocity vector (to x-axis) θ Γ the fraction $(\gamma + 1)/(\gamma - 1)$ molar density of species X (kmole m^{-3}) [X]

INDICES

- ()_0 stagnation conditions
- $()_1$ nozzle (diffuser) exit conditions
- diffuser entry conditions $()_{2}$
- $()_t$ Eulerian time derivative
- ()_x () Eulerian space derivative
- Lagrangian time derivative

1. INTRODUCTION

In recent years a study of the gasdynamics of space-based HF/DF laser exhaust plume was conducted at the NPS. The aim of this program was to identify phenomena that give rise to a potentially contaminating backflow of corrosive species (HF, DF, F), and to estimate the magnitude of the flux arriving at the spacecraft [1, 2, 3, 4]. The laser was envisioned as a cylindrical spacecraft having a centrally located nozzle of ring-symmetry. This is an idealization of a more general zero-thrust exhaust configuration for an open loop HF/DF laser (Fig. 1-1).

In former studies [2, 3] we focused on the contribution of thermal self-scattering to a contaminating backscattered flux of corrosive molecules (HF, DF) from the exhaust plume. It was shown that this flux emanates primarily from the lip-centered rarefaction fans that flank the exhaust plume, and it was estimated that at a sufficiently high exit Mach number (e.g. $M_1 = 4$), the thermally backscattered flux of HF + DF is utterly negligible.

The purpose of this report is to present a study of the effect of diffuser start-up flow, including the ongoing recombination of atomic hydrogen, on the thermally backscattered flux. Our main conclusion is that by designing for a sufficiently high steady exit Mach number (e.g. $M_1 = 4$), the level of thermally backscattered flux of corrosive molecules (HF + DF) would be negligible even when the combined effects of hydrogen recombination and transient flow are considered.

The diffuser is simplified as a cylindrically expanding channel of uniform width, and the flow is idealized as inviscid expansion of a perfect gas with an ongoing reaction of hydrogen recombination. The flow is computed as one-dimensional time-dependent.

A fully 2-D time-dependent computation of an emerging exhaust plume is outside the scope of the present laser exhaust study. Rather, we resort to semi-quantitative arguments that lead to an upperbound estimate of the effect of transient flow on thermal backscattering, by showing that the transient turning angle in an expansive corner flow can be estimated as higher than the corresponding steady flow turning angle. It is subsequently suggested that an overestimate to the the backscattered flux from a transient plume is obtained by considering it as a steady plume whose exit velocity vector is pre-rotated so that its limiting (vacuum) streamline coincides with that defined by the transient turning angle. The plan of this report is the following. In Ch. 2 we present our radial (1-D) diffuser model based on the linear configuration of the TRW test laser [5], and we propose a "typical case" of HF/DF laser flow based on one of those tests. Ch. 3 is devoted to the gasdynamic governing equations, including the hydrogen recombination rate. The resulting diffuser model was implemented in a 1-D Euler code (named HFL) which utilizes the GRP scheme for integrating the conservation laws of compressible flow [6]. The HFL code is given in Appendix A. The results of a typical diffuser startup flow are presented in Ch. 4, along with a discussion and analysis of the effects of transient flow and uncertainty in the hydrogen recombination rate on thermally backscattered flux of HF+DF. We also consider kinetic backscattering of HF or DF molecules caused by third-body recoil in the hydrogen recombination. It is shown that the combined contribution of these effects to backscattered flux remains negligible in the typical case. Chapter 4 ends with some concluding remarks, and references are brought in Ch. 5.



Figure 1-1.

Ring-Symmetric HF DF Laser Exhaust Plume

2. THE DIFFUSER FLOW MODEL

Our diffuser model is based on a schematic radial laser configuration as shown in Fig. 2-1. The major components in this design concept are those present in an experimental HF/DF open loop laser tested at TRW [5]. In this chapter we describe the radial configuration including the diffuser (Section 2.1), then we present a typical HF/DF laser flow based on one of those TRW tests (Section 2.2).

2.1 Radial Laser Configuration

We assume that an open loop HF/DF laser of the type tested at TRW [5], can be rearranged in a radial (rather than linear) sequence, where the flow begins at the hub and proceeds in an outward radial direction. Referring to Fig. 2-1, the major components of this configuration are :

- (a) Combustion Chamber : Deuterium and fluorine burn with excess fluorine, resulting in hot gaseous mixture where fluorine is virtually completely dissociated.
- (b) Nozzle Cascade : Rapid expansion to supersonic flow leaves atomic fluorine concentration effectively frozen.
- (c) $H_2 + He$ Injection : Mixture is injected between the supersonic streams of DF + F emerging from the cascade.
- (d) Mixing and Lasing : The lasing is from vibrationally excited HF molecules produced by direct reaction between H_2 and F. As a by-product, one H atom is produced for every HF molecule.
- (e) Diffuser Entrance : This point marks the end of the lasing process. From this point on the flow is just an exhaust to be discarded safely.
- (f) Radial Diffuser : The purpose of the diffuser is to raise the flow Mach number at the exit so that no appreciable backflow from the exhaust plume will take place [2, 3, 4]. It should be noted that a desirable diffuser area ratio can be achieved at lower radius ratios by letting the diffuser expand in the axial direction.

2.2 Typical Laser Flow

We chose as a typical laser flow one of the tests conducted in the TRW experiments [5] it is test III in Table 5 (p. 91) of that reference. The mole fraction and corresponding average molecular weight and specific-heat ratio (W and γ) at the diffuser entrance for this test were :

Mole fractions	$f_{\rm H} = .091 f_{\rm HI}$ $f_{\rm DF} = .135 f_{\rm H}$	F = .091 f $I_e = .579$	$H_2 = .104$	(2.2.1)
Average molecular weight	W = 7.27			(2.2-1)
Specific-heat ratio	$\gamma = 1.54$			

The additional data required for the computational model is the flow variables at the diffuser entrance. Some of these variables have been measured directly or indirectly and the remaining variables can be evaluated from standard isentropic flow relations for compressible flow of an ideal gas. The data given in the TRW tests report [5] are :

```
Diffuser entrance cross-section is : 1^{"} \times 7^{"}

Mass flow rate is : 14.99 (gr sec<sup>-1</sup>)

Stagnation temperature is : 1400 (K)

Flow velocity is : 2300 (m sec<sup>-1</sup>)
```

Flow density is now obtained as the ratio of the specific mass flow rate and the velocity. Then Mach number is extracted from the standard relations between Mach number, velocity and stagnation temperature. The values of these variables are :

$$M_2 = 2.26$$

 $\rho_2 = 1.44 \times 10^{-3} \text{ (kg m}^{-3)}$ (2.2-3)
 $P_2 = 9.72 \times 10^{-4} \text{ (MPa)}$

The flow at the diffuser entrance is thus fully specified for the selected typical case. In the next chapter we take up the matter of computing the transient expansion following an abrupt start-up of the diffuser inflow.



Figure 2-1. Radial Configuration of HF/DF Open-Loop Laser

3. THE GASDYNAMIC FLOW MODEL

The transient expansion of the lasing products following an abrupt start-up of inflow at the diffuser entrance, is idealized as an inviscid compressible flow of a mixture of perfect gases with one ongoing chemical reaction - that of hydrogen recombination. The computational model thus calls for a formulation of the governing equations and for a numerical scheme capable of integrating them in time and space.

In this chapter we describe the governing equations for the diffuser flow (Section 3.1), following by a simple approximation chosen for the hydrogen recombination rate as a three body reaction (Section 3.2). The numerical scheme employed for the solution is of the Generalized Riemann Problem (GRP) type [6]. This scheme has been implemented in a code which was adapted to the diffuser flow case. The code (named HFL) and some brief description of features introduced to treat hydrogen recombination are given in Appendix A. In a recent report [7] a very similar version of this code (without chemical reaction) was described in considerable detail.

3.1 The Governing Equations

The expansion of lasing products through the diffuser is governed by the Euler equations for a gaseous mixture of ideal gases with ongoing hydrogen recombination reaction. We write these equations in the quasi-one-dimensional format of flow in a stream tube of varying cross-section area A(x), but in actual computations we set A(x) = x, thereby reducing the equations to the cylindrical case. (The code HFL, however, can accept any smooth A(x)).

We chose to simplify the designation of atomic hydrogen mole fraction by normalizing it as $f_H Z(x,t)$, where f_H is the mole fraction at the diffuser entrance (it is constant) and Z(x,t) denotes the degree of dissociation (Z=1 is maximum concentration of H at the diffuser entrance, Z=0 is complete recombination). As an approximation, we assume that W and γ are constant throughout. In the typical case (2.2-1), γ and W can vary by as much as 1% and 4% respectively at full recombination. Neglecting that variation is consistent with the preliminary nature of the present diffuser flow analysis.

The governing equations are the three standard conservation laws (mass, momentum and energy), and an additional species conservation law for atomic hydrogen. The conservation laws are

augmented by an equation of state (ideal gas) and by a rate law for hydrogen recombination. The full system of equations is :

Mass	$\left[A\rho\right]_{t} + \left[A\rho U\right]_{x} = 0$	
Species H	$\left[A\rho Z\right]_{t} + \left[A\rho U Z\right]_{x} = A\rho \dot{Z}$	
Momentum	$[A\rho U]_{t} + [\rho U^{2}]_{x} + AP_{x} = 0$	(3.1-1)
Energy	$\left[AE\right]_{t} + \left[A(E+P)U\right]_{x} = 0$	
Equation of State	$P(\rho, E, Z,) = (\gamma - 1) [E - \rho U^2/2 - (\rho f_H Z/W)Q_H]$	
Recombination Rate	$\dot{Z} = \dot{Z}(\rho, P, Z)$	

where A is a function solely of x, and ρ , U, P, E, Z are all functions of (x,t). The normalized rate function is \mathring{Z} . Its derivation and explicit expression are given in Section 3.2.

We note that the energy equation contains the heat released by hydrogen recombination $(Q_H \text{ per mole of } H)$ in an implicit way, by defining the total energy as including the latent heat due to recombination, in addition to internal and kinetic energy terms.

3.2 Hydrogen Recombination

The hydrogen recombination is commonly assumed to be a three-body reaction [8], with the following rate law:

$$H + H + M \rightarrow H_{2} + M$$

$$[\dot{H}_{2}] = -k_{0} [H]^{2} [M]$$

$$k_{0} = 7 \times 10^{15} [(mole/cm^{3})^{-2} sec^{-1}]$$
(3.2-1)

where by \mathbf{M} we denote a third molecule, which in our case may be any molecule in the gaseous mixture (including \mathbf{H}).

The value we chose for k_0 is an upper limit of a range of values recommended by Kondratiev [9] for the reaction H + H + He (from 2×10^{15} to 7×10^{15}), since in the typical case helium constitutes about 58% of the molecules in the lasing products.

The data compiled by Kondratiev [9] indicates a comparable range of variation with temperature as with the third species M. We later introduce uncertainty factors of 10 and 100, which in all likelihood more than reflect the uncertainty in the reaction rate for hydrogen recombination.

It is convenient to redefine the reaction rate in terms of flow density ρ and normalized H concentration Z. The modified rate constant k_1 is given by :

$$\dot{Z} = -k_1 \rho^2 Z^2$$

(3.2-2)

 $k_1 = 2 k_0 f_H / W^2$

where the factor 2 is due to the fact that the rate of depletion of H is twice the rate of production of H_2 . In deriving (3.2-2) we made use of the relations $f_H = [H]_2/[M]_2$ and $[M] = \rho/W$, where index 2 denotes the diffuser entrance.

The heat of formation released per mole of recombined H_2 is 435.783 (kJ mole) according to [10] (page F-179 in that reference). In the code we use the energy parameter per unit mass of the gaseous mixture Q_{DET} , defined as :

$$Q_{\text{DET}} = Q_{\text{H}} f_{\text{H}} / W$$
 (3.2-3)
 $Q_{\text{H}} = 435.783 / 2$ (KJ/mole)

4. **RESULTS AND DISCUSSION**

Several numerical computations of the transient diffuser flow were performed using the code HFL (Appendix A). The flow was started by an abrupt inflow at the diffuser inlet; the radial diffuser model and the typical HF/DF laser case (Sections 2.1 and 2.2) were assumed. Due to uncertainty in hydrogen recombination rate, three rate levels were assumed : the nominal level (3.2-1), a tenfold increased rate and a hundredfold increased rate.

We are primarily concerned with the thermally backscattered flux arriving at the surface from the exhaust plume. Our goal is to show that by choosing a diffuser with a sufficiently high steady exit Mach number, the backscattered flux can be negligibly low even when the combined effects of hydrogen recombination and transient exit flow are taken into account. Put in other words, we present a simplified analysis of the transient exhaust flow, which enables the establishment of a reasonable margin on a frozen/steady design for low backscattered flux. This analysis is presented in Section 4.1 below.

The continuation of the hydrogen recombination reaction into the plume may give rise to a contaminating backflow of a different kind. The velocity imparted to the "third body" molecule in the hydrogen recombination process (Eq. 3.2-1) may be large enough to overcome the radial flow velocity component, resulting in molecular backflow. This effect is discussed in Section 4.2, and it is shown to be potentially capable to give rise to an HF/DF deposition rate of the order of 1 molecular monolayer per hour.

4.1 Thermal Backscattering

Since in steady flow thermally backscattered flux is linked primarily to exit Mach number, we focus our attention on the time-history of the exit Mach number obtained from the diffuser start-up computations mentioned above. Two major features are noted in these results (Fig. 4-1).

The first feature is the monotonic decrease in exit Mach number with time, as the flow within the diffuser undergoes transition from an initial "cloud expansion" mode to a steady expansion flow in a channel of increasing cross-section area. A steady exit flow seems to be established after about 2 (ms) from the start-up instant. The second feature is related to the heat released in the flow by hydrogen recombination. As the recombination rate is increased, so does the time-asymptotic value

of the exit recombination fraction. The recombination fractions in the three cases (Fig. 4-1) are 1% of 7% and 46%; the corresponding exit Mach numbers are 4.0, 3.69 and 2.81. This trend is in qualitative agreement with the well known phenomenon of decrease in Mach number as a result of heat addition to a steady supersonic flow in a channel of uniform cross-section [11].

Estimates of recombination rates are notoriously uncertain. How can a reasonable uncertainty factor be established? We do not know of an estimate of this factor for the flow of HF DF laser products. However, in another case of flow involving hydrogen recombination - that of hydrazine rocket motors - a recent study [12] recommends a hydrogen recombination rate of $2.8 \times 10^{17}/T$ (in c.g.s. K units) and an uncertainty factor of 30. Assuming the relatively low temperature of T = 300 (K) and multiplying by 30, we get a recombination rate of 3×10^{16} , versus 7×10^{16} in our tenfold case. This demonstrates that the tenfold case is already reasonably high; just the same, we also retain the hundredfold case in the upcoming discussion.

The exit Mach number time-histories (Fig. 4-1) demonstrate that the nominal diffuser flow is nearly frozen (exit recombination fraction 1% and Mach number 4); even in the tenfold case the flow is not dominated by hydrogen recombination (exit recombination fraction 7% and Mach number 3.69). This conclusion is in agreement with findings of the TRW HF/DF laser study [5]. It takes the unrealistically high hundredfold increase in hydrogen recombination rate to produce a decisive change in the steady diffuser flow (exit recombination fraction 46% and Mach number 2.81).

One role of the diffuser is to expand the laser exhaust to a sufficiently high exit Mach number, so that the thermally backscattered flux of corrosive molecules (HF, DF) is negligibly small. Let us consider the nominal case ($M_1 = 4$) and denote by "reference flux" the combined HF+DF backscattered flux arriving at a point located at 0.1 (m) from the nozzle lip (Fig. 1-1). Using the code RINGBD based on the breakdown surface model [2], the nominal reference flux was evaluated as 3.1×10^5 (molecules m⁻² sec⁻¹). This flux level corresponds to a surface deposition rate (assuming the sticking coefficient equals 1) of about 10⁻¹⁰ molecular monolayers per hour, which is utterly negligible (a reasonable estimate of total operating time would not exceed several hours).

Observing that a steady exit flow has been established in all three cases by about t=2 (ms) (see Fig. 4-1), we suggest that an approximate estimate of the backscattered flux would be obtained by assuming a steady flow at the diffuser exit and the exhaust plume. The RINGBD computations of the increase hydrogen recombination rate cases yielded the following results. In the tenfold case $(M_1 = 3.69)$ the flux was 10^2 times larger than the nominal reference flux. In the hundredfold case

 $(M_1 = 2.81)$ the flux increase was by a factor of 10^7 . Even in the unrealistically high hundredfold case, that flux level corresponds to about 10^{-3} monolayers per hour, which is still negligible.

What other uncertainties could affect the foregoing conclusion? First we consider the effect of variations in stagnation temperature and density relative to the nominal case, then we take up the matter of transient plume flow.

Exit stagnation temperature was observed to vary in the HFL diffuser start-up computations by a factor of no more than about 1.3. Since all velocities in the breakdown surface model are normalized by speed of sound [2], the flux is proportional to the square root of the stagnation temperature. Also, it has been shown [2] that a change in stagnation density can produce an inversely proportional change in flux. Stagnation density was reduced by a factor of about 1.3 in the tenfold case and about 2.8 in the hundredfold case. In either case the potential effect on flux is small relative to changes brought upon by reduced exit Mach number, so we attribute the drastic change in flux following an increased hydrogen recombination rate primarily to the reduced exit Mach number.

We now address the effect of transient plume flow. Since the exit Mach number is monotonically decreasing with time (Fig. 4-1), and since other flow variables do not appreciably affect the flux from a steady plume, we suggest that an upper bound on the effect of transient plume flow can be established by linking it to a "transient turning angle", larger than that corresponding to a steady flow with the same exit Mach number. Obviously, if a Prandtl-Meyer flow pattern is derived from a flow which exits the nozzle at an angle lower than 90°, its limiting turning angle would bring it closer to the spacecraft surface, and with a lower outward radial velocity to overcome, more molecules would be thermally backscattered. Thus, we regard the transient flow around the nozzle lip as represented by an equal exit Mach number steady flow, with some initial exit turning angle.

The justification for this model is the following "upper bound" estimate for the transient turning angle of an emerging exhaust plume. The exit velocity vector U_1 is visualized as rotating by a gradual turning of the plume/vacuum interface until it reaches the normal velocity $(2/(\gamma-1))C_1$ (Fig. 4-2), which corresponds to a plane-wave expansion into vacuum. The corresponding turning angle is $\alpha = (2/(\gamma-1))C_1/U_1 = (2/(\gamma-1))/M_1$. It is an overestimate of the turning angle since in a steady corner expansion (and also in a nonsteady one) the magnitude of the velocity vector increases as it rotates, in order to conserve stagnation enthalpy (or even increase it in nonsteady flow about an expansive corner).

It is of interest to note that α as given above is identical with the first term of a power series expansion in $1/M_1$ of the standard Prandtl-Meyer expression for the limiting turning angle [13]. Let us denote by $\Delta \alpha$ the increment of the unsteady turning angle relative to the corresponding steady one (Prandtl-Meyer). This (positive) increment is given by :

$$\Delta \alpha = (2/(\gamma - 1))/M_1 - \left\{ \Gamma^{1/2} \arctan \left[\Gamma^{1/2} (M_1^2 - 1)^{-1/2} \right] - \arctan \left[(M_1^2 - 1)^{-1/2} \right] \right\}$$

$$(4.1-1)$$

$$\Gamma = (\gamma + 1)/(\gamma - 1)$$

We now argue that the flux ratio between a steady flow and the same flow with exit velocity rotated by $\Delta \alpha$ is an upper-bound estimate to the effect of transient plume flow with the same exit variables. We note that by pre-rotating the steady corner flow, we make the limiting streamline in the steady case, coincide with the nonsteady plume/vacuum interface deemed to have rotated through the angle α .

The stage is now set to estimate the transient flux increase factors in the three hydrogen recombination rate cases (exit Mach numbers 4, 3.69 and 2.81). Using Eq.(4-1) we get the turning angle increments of $\Delta \alpha = 4.1^{\circ}$, 5.1° and 10.6° respectively. Re-computing the reference flux (code RINGBD) in these cases with initial exit angle of 90° – $\Delta \alpha$, we get the flux increase factors of 2.7, 3.5 and 10 respectively. Even in the worst case (hundredfold), the flux would increase from 10⁻³ to 10⁻² monolayers per hour, which is still negligibly small.

We also notice that the flux increase factor resulting from the decrease in exit Mach number due to higher hydrogen recombination rate, is much larger than the factor representing the effect of transient plume flow in the same case. Thus, in the tenfold case these factors are 10^2 versus 3.5, and in the hundredfold case the ratio is even higher : 10^7 versus 10. We conclude that the transient effect is quantitatively secondary to the effect of exit Mach number, which is thus established as the major parameter for designing an exhaust with a negligible level of thermally backscattered HF+DF flux.

4.2 Kinetic Backscattering

The role of the third body in the hydrogen recombination reaction (3.2-1) is to absorb the energy released by the recombination process while maintaining the combined pre-collision momentum of the participating molecules. Assume the momentum added to [M] is q, then the momentum added to H_2 is -q. Denote by m_1 the mass of H_2 , by m_2 the mass of HF and by e the energy released due to the recombination. Then q is determined from the following energy conservation relation :

$$q^{2}/2m_{1} + q^{2}/2m_{2} = e$$

 $m_{1} = 2$ $m_{2} = 20$ $e = 4.36 \times 10^{8}$ (Joules kmole)
 $U = q/m_{2} = 2000$ (m/sec)
(4.2-1)

The values used in the computation above are per kmole, but the result is the same as using values pertaining to single molecules. Since the velocity obtained upon expansion to zero-pressure in the typical case is about 3000 (m/sec), our results imply that a turning angle in excess of $\arccos(2/3) = 48^{\circ}$ is needed in order to enable some kinetically backscattered molecules to reach the spacecraft.

In the nominal case the turning angle is 49° and in the tenfold case it is 52°. Also, some kinetically backscattered molecules can originate from within the rarefaction fan, since the exit velocity in the typical case is only about 1500 (m sec⁻¹) (versus 2000 (m sec⁻¹) velocity increment to kinetically scattered HF molecules). Consequently, this effect may contribute to spacecraft contamination, and its magnitude should be estimated. It will become progressively more significant at lower exit Mach number, and thus may be an additional factor in determining a minimal value of this flow variable.

While we do not presently attempt at an exact integration of the flux of kinetically backscattered molecules arriving at each surface point, we propose the following overestimate of its magnitude. Consider the outgoing flux of kinetically scattered HF molecules from a half-space of quiescent uniform gas having the thermodynamic properties of the nozzle exit in the typical case. Consider the hydrogen recombination rate equation (3.2-1), and substitute $[X] = f_X n/A_v$. This equation then reads as the volume rate of hydrogen recombinations (denoted as g_c below). In a slab of quiescent gas, half the kinetically scattered molecules have an outward pointing velocity vector in one direction. The probability of collisionless passage out of the slab is $\exp(-x/\lambda)$, so that the outgoing flux **F** is given by :

$$F = g_c \lambda/2$$

$$g_{c} = k_{0} n^{3} A_{v}^{-2} f_{H}^{2} (f_{HF} + f_{DF})$$
(4.2-2)

Using typical case exit conditions $n_1 = 2.81 \times 10^{22}$ (m⁻³) and mean free path $\lambda_1 = 1.28 \times 10^{-4}$ (m), we get $F = 5.14 \times 10^{16}$ (m⁻² sec⁻¹), or about 12 monolayers per hour. Since only a small fraction of this flux actually arrives at spacecraft surface points, the arriving flux is in all likelihood well below 1 monolayer per hour. If this flux level is deemed significant, an accurate integration of kinetically scattered flux emanating from the exhaust plume should be performed. The details of such scheme are analogous to the first-collision ambient scattering model [4], since both effects result in a source-like distribution throughout the plume, and both involve a steric factor (one half in the quiescent gas above) related to the vector addition of flow velocity and velocity imparted through ambient collision or assistance in hydrogen recombination. Therefore, the two effects can conveniently be unified under a common framework.

4.3 Concluding Remarks

From the foregoing analysis and discussion we conclude that a design for low (negligible) level of thermally backscattered flux of HF+DF can be accomplished by assuming steady frozen exhaust flow. The effects of transient diffuser/plume flow and hydrogen recombination may typically increase that flux by a factor of 10^2 . Given the sensitivity of flux to exit Mach number, an adequate margin can readily be achieved by raising the exit Mach number. In the typical case presented here, an exit Mach number of 4 has been shown to be adequate.

It should be noted that transient effects originating from points upstream of the diffuser entrance were not considered here, as they depend on details of the system construction and operating sequence.

The kinetic scattering effect has been pointed out as an additional potential source of contaminating backflow. It is the result of hydrogen recombination collisions assisted by an IIF or DF molecule as third body. The HF/DF molecule receives part of the kinetic energy release by the hydrogen recombination.



Figure 4-1. Mach Number at Diffuser Exit for Reactive Transient Flow



Figure 4-2. Rotation Angle for Non-Steady Plume (Overestimate)

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5.

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APPENDIX A. The HFL Code

A.1 Features Specific to Diffuser Flow Model

The purpose of this appendix is to provide the listing of the HFL code used in the diffuser flow computations. An almost identical code was recently described in some detail [7], the major modification for HFL being the addition of hydrogen recombination.

The highlights of the HFL version to the GRP code [7] are as follows (numbers in parenthesis refer to statement numbers which are prefixed by HFL in the listing).

(a) Data (NETUNM):

The data which relates specifically to the diffuser flow with hydrogen recombination is given in statements (194 - 239). Some parameters are stored in /DIFFUS/ (129) for use in BEGIN and SAFAE.

(b) Initial Conditions (BEGIN) :

The initial conditions are ideally an empty diffuser. As an approximation we set small pressure and density (270 - 271) and a positive velocity (277) as initial values. The velocity reduces the intensity of the shock driven into the dilute initial gas by the abrupt start-up of inflow at the diffuser entrance (I = 2). Note that the initial value of the total energy E(I) is augmented by the heat of formation of hydrogen (306). The heat term is subsequently subtracted from the total energy in order to compute the pressure (see (d) below).

The grid is defined as follows. The number of cells (L-2) is L-2 = 50 (24). The diffuser extends from X0 = 0.625 to X1 = 3.125 (283 - 284), so that DX = 0.05. Since the external radius of the spacecraft is just 2.5, this grid consists of 40 cells within the diffuser and 10 cells in an extended segment. The purpose of this extended segment is to minimize any propagation of error due to imperfection of the outflow boundary condition (see (c) below). Since the ambient pressure is zero, this additional segment does not affect the flow at $X \le 2.5$. Consequently, the results for the diffuser exit flow were read from cell I = 39 whose midpoint is X = 2.5.

(c) Boundary Conditions (SAFAE) :

The inflow is set by assigning the diffuser entrance conditions to cell I = 1. The outflow is set by extrapolating (with zero gradient) the flow from the inner boundary cell (I = L-1) to the boundary cell I = L.

(d) Conservation Laws (CYCEUL) :

Here all four conservation laws are integrated in time. There is an added equation of a "time-split" scheme for solving the conservation of H species equation. It is first solved without the recombination rate term (459), then the change in Z(I) due to recombination during that time step is added as DZZ (501 - 502).

The energy equation includes the contribution of the formation energy indirectly. This equation has the same format as the adiabatic one (491), but when QDET.GT.0, the internal energy (505) is affected by changes in Z(I) and as a result the pressure P(I) (516) is also affected by progress in the recombination reaction.

A.2 Code Listing

```
C$OPTIONS LIST -
                                                                                     HFL0001
       IMPLICIT REAL*8(A-H, 0-Z, $)
                                                                                     HFL0002
С
   PROGRAM DETO
                                                                                     HFL0003
Ĉ
   HFL --
            HF/DF LASER DIFUSER TRANSIENT FLOW.
                                                                                     HFL0004
       COMMON B(52,26)
                                                                                     HFL0005
       , ENDB
COMMON / AB/A(50)
      1
                                                                                     HFL0006
                                                                                     HFL0007
       EQUIVALENCE (L,A(1)),(LL,A(2)),(T,A(3)),(DT,A(4)),(TMAX,A(5)),
(TMUD,A(6)),(DTMUD,A(7)),(JOB,A(8)),(NERI,A(9)),
                                                                                     HFL0008
                                                                                     HFL0009
      1
                     (JJJ,A(10)),(KEYMON,A(11)),(NCYC,A(12))
      2
                                                                                      HFL0010
       EQUIVALENCE
                    (COLELA,A(13))
                                                                                     HFL0011
       EQUIVALENCE
                    (LAGEUL, A(14))
                                                                                      HFL0012
       EQUIVALENCE (UGAL, A(15))
                                                                                      HFL0013
       EQUIVALENCE (KEYEK, A(16))
                                                                                      HFL0014
       EQUIVALENCE (NCYCPR,A(17))
EQUIVALENCE (STAB,A(18)),(DTBA,A(19)),(DTKOD,A(20)),(KDT,A(21))
                                                                                      HFL0015
                                                                                      HFL0016
       COMMON /MONIT/NC14(4), CASEAV(4), NF16(6),
                                                                                      HFL0017
                          NMONU(4), NMONP(4), NMONG(4), NMONRO(4), NMONZ(4)
                                                                                      HFL0018
     1
DO 20 N=1,30
                                                                                     HFL0020
С
Č20
       NC14(N) = 0
                                                                                      HFL0021
                                                                                      HFL0022
       NMAT = 26
С
       L=(LOCF(ENDB)-LOCF(B(1,1)))/NMAT
                                                                                      HFL0023
                                                                                      HFL0024
       L=52
       LL = L - 1
                                                                                      HFL0025
                                                                                      HFL0026
       NN=NMAT×L
       DO 1 I=1,L
DO 1 II=1,NMAT
                                                                                      HFL0027
                                                                                     HFL0028
       B(I,II)=0.
                                                                                      HFL0029
 1
       CALL MAINO(L,B(1, 1),B(1, 2),B(1, 3),B(1, 4),B(1, 5),
B(1, 6),B(1, 7),B(1, 8),B(1, 9),B(1,10),
B(1,11),B(1,12),B(1,13),B(1,14),B(1,15),
                                                                                     HFL0030
                                                                                     HFL0031
      1
      23
                                                                                      HFL0032
                                                                                      HFL0033
                     B(1,16),B(1,17),B(1,18),B(1,19),B(1,20),
     ž
                     B(1,21),B(1,22),B(1,23),B(1,24),B(1,25),
                                                                                      HFL0034
      5
                     B(1,26))
                                                                                      HFL0035
                                                                                      HFL0036
       STOP
                                                                                      HFL0037
       END
       SUBROUTINE MAINO
                                                                                      HFL0038
                      (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,
US,PS,UIDOT,PIDOT,
                                                                                      HFL0039
      1
      ž
                                                                                      HFL0040
                                                                                      HFL0041
      ×
                      FIMZ, ZMDOT,
      3
                        TENA, FIRO, FIM, FIE, GIP, VOL, Z, DZ)
                                                                                      HFL0042
       IMPLICIT REAL*8(A-H, 0-Z, $)
                                                                                      HFL0043
       DIMENSION X(L), U(L), P(L), RO(L), G(L), E(L), DU(L), DP(L), DRO(L),
                                                                                      HFL0044
      1
                   DG(L), DXSI(L), MIN(L),
                                                                                      HFL0045
                   US(L), PS(L), UIDOT(L), PIDOT(L)
      2
                                                                                      HFL0046
                  ,TENA(L),FIRO(L),FIM(L),FIE(L)
,GIP(L),VOL(L),Z(L),DZ(L)
                                                                                      HFL0047
      3
      4
                                                                                      HFL0048
                                                                                      HFL0049
      5
                  ,FIMZ(L),ZMDOT(L)
       COMMON /AB/A(50)
                                                                                      HFL0050
       EQUIVALENCE (LL,A(2)),(T,A(3)),(DT,A(4)),(TMAX,A(5)),
(TMUD,A(6)),(DTMUD,A(7)),(JOB,A(8)),(NERI,A(9)),
                                                                                      HFL0051
                                                                                      HFL0052
      1
                                                                                      HFL0053
      2
                     (JJJ,A(10)),(KEYMON,A(11)),(NCYC,A(12))
       EQUIVALENCE (LAGEUL,A(14))
EQUIVALENCE (NCYCPR,A(17))
EQUIVALENCE (NCYCPR,A(17))
EQUIVALENCE (STAB,A(18)),(DTBA,A(19)),(DTKOD,A(20)),(KDT,A(21))
                                                                                      HFL0054
                                                                                      HFL0055
                                                                                      HFL0056
                                                                                      HFL0057
       COMMON /TOT/AMTOT, ETOT, EKTOT, EPTOT, TENTOT
HFL0059
       T = 0
       NCYC=0
                                                                                      HFL0060
                                                                                      HFL0061
       JJJ=0
                                                                                      HFL0062
       CALL NETUNM
                                                                                      HFL0063
       DELT=DT
                                                                                      HFL0064
       CALL BEGIN
                       (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,
                                                                                      HFL0065
      1
                        US, PS, UIDOT, PIDOT,
                                                                                      HFL0066
      2
                                                                                      HFL0067
      ¥
                       FIMZ, ZMDOT,
                        TENA, FIRO, FIM, FIE, GIP, VOL, Z, DZ)
                                                                                      HFL0068
      3
                                                                                      HFL0069
       CALL SAFAE
                      (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,
US,PS,UIDOT,PIDOT,
                                                                                      HFL0070
      12
                                                                                      HFL0071
                       FIMZ, ZMDOT,
                                                                                      HFL0072
      ¥
```

```
22
```

A1

```
3
                      TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ)
                                                                                 HFL0073
      NCYC=NCYC+1
 1
                                                                                 HFL0074
С
 TIME STEP CONTROL.
                                                                                 HFL0075
      DT = DTBA
                                                                                 HFL0076
      IF(DT.GT.1.1D0*DTKOD.AND.DTKOD.NE.0.) DT=1.1D0*DTKOD
                                                                                 HFL0077
      IF(NCYC.EQ.2) DT=DT/10.
                                                                                 HFL0078
      IF (NCYC.EQ.1) DT=0.
IF(DT.EQ.0.) GO TO 11
                                                                                 HFL0079
                                                                                 HFL0080
      NHAD=((TMUD-T)/DT-1.D-10)
                                                                                 HFL0081
      IF(NHAD.GE.10) GO TO 11
                                                                                 HFL0082
      DT=(TMUD-T)/DFLOAT(NHAD+1)
                                                                                 HFL0083
 11
      CONTINUE
                                                                                 HFL0084
      T=T+DT
                                                                                 HFL0085
      IF((NCYC/NCYCPR)*NCYCPR.NE.NCYC.AND.NCYC.GT.NCYCPR) G0 T0 33
                                                                                 HFL0086
      PRINT 10, NCYC, T, DT, KDT
FORMAT(1X, 'NCYC=', I4, 3X, 'T=', D11.4, 3X, 'DT=', D11.4, 3X, 'KDT=', I4)
                                                                                 HFL0087
 10
                                                                                 HFL0088
 33
      CONTINUE
                                                                                 HFL0089
      DTBA=DTMUD
                                                                                 HFL0090
      KDT=0
                                                                                 HFL0091
      NERI=1
                                                                                 HFL0092
      IF (DABS(T-TMUD).LT.1.D-8) NERI=0
                                                                                 HFL0093
      CALL CYCEUL
                                                                                 HFL0094
                     (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,
US,PS,UIDOT,PIDOT,
     1
                                                                                 HFL0095
     2
                                                                                 HFL0096
     ¥
                     FIMZ, ZMDOT,
                                                                                 HFL0097
     3
                      TENA, FIRO, FIM, FIE, GIP, VOL, Z, DZ)
                                                                                 HFL0098
      CALL SAFAE
                                                                                 HFL0099
                                                                                 HFL0100
                     (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,
     1
     2
                      US, PS, UIDOT, PIDOT,
                                                                                 HFL0101
     ¥
                     FIMZ, ZMDOT,
                                                                                 HFL0102
                      TENA, FIRO, FIM, FIE, GIP, VOL, Z, DZ)
     3
                                                                                 HFL0103
      IF (NERI.NE.0) GO TO 2
                                                                                 HFL0104
      CALL PRINT
                                                                                 HFL0105
                     (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,
                                                                                 HFL0106
     1
     2
                      US, PS, UIDOT, PIDOT,
                                                                                 HFL0107
                                                                                 HFL0108
                     FIMZ, ZMDOT,
     ×
                      TENA, FIRO, FIM, FIE, GIP, VOL, Z, DZ)
     3
                                                                                 HFL0109
      IF (DABS(T-TMUD).LT.1.D-8) TMUD=TMUD+DTMUD
                                                                                 HFL0110
 2
                                                                                 HFL0111
      CONTINUE
                                                                                 HFL0112
      DTKOD=DT
                                                                                 HFL0113
      IF (T.LT.TMAX-1.D-8) GO TO 1
      RETURN
                                                                                 HFL0114
                                                                                 HFL0115
      END
                                                                                 HFL0116
      SUBROUTINE NETUNM
      IMPLICIT REAL *8(A-H, 0-Z, $)
                                                                                 HFL0117
      COMMON /AB/A(50)
                                                                                 HFL0118
      EQUIVALENCE (L,A(1))
EQUIVALENCE (LL,A(2)),(T,A(3)),(DT,A(4)),(TMAX,A(5)),
                                                                                 HFL0119
                                                                                 HFL0120
                    (TMUD, A(6)), (DTMUD, A(7)), (JOB, A(8)), (NERI, A(9)),
     1
                                                                                 HFL0121
     2
                    (JJJ,A(10)),(KEYMON,A(11)),(NCYC,A(12))
                                                                                 HFL0122
                                                                                 HFL0123
      EQUIVALENCE (COLELA, A(13))
      EQUIVALENCE (LAGEUL, A(14))
                                                                                 HFL0124
                                                                                 HFL0125
      EQUIVALENCE (KEYEK, A(16))
      EQUIVALENCE (NCYCPR,A(17))
EQUIVALENCE (STAB,A(18)),(DTBA,A(19)),(DTKOD,A(20)),(KDT,A(21))
HFL0126
COMMON/DETO/QDET,TC,RATE,PCJDET,RCJDET,UCJDET,DCJDET,PODET,ROODET HFL0128
      COMMON/DIFFUS/U2,P2,R02,ARW
                                                                                 HFL0129
                                                                                 HFL0130
      COMMON /DRAW/GODELX,GODELY,UMIN,UMAX,PMIN,PMAX,ROMIN,ROMAX
                                                                                 HFL0131
                     ,XMIN,XMAX,SMIN,SMAX,IVERSA
     1
      COMMON / GAM/GAMA, NG, MU2, G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11
                                                                                 HFL0132
                 ,G12,G13,G14,G15,G16,G17,G18,G19,G20
                                                                                 HFL0133
     1
                                                                                 HFL0134
      REAL×8 NG
                                                                                 HFL0135
      REAL *8 MU2
                                                                                 HFL0136
      NAMELIST /IN/LIN, GAMA, DT, TMUD, DTMUD, TMAX,
                     GODELX, GODELY, UMIN, UMAX, PMIN, PMAX, ROMIN, ROMAX,
                                                                                 HFL0137
     1
                     SMIN, SMAX, IVERSA, KEYMON, COLELA, STAB
                                                                                 HFL0138
     2
                                                                                 HFL0139
     3
                    ,LAGEUL,KEYEK
                    ,QDET,TC,RATE
                                                                                 HFL0140
     4
HFL0142
      LIN=L
                                                                                 HFL0143
      LAGEUL=2
                                                                                 HFL0144
      NCYCPR=20
```

:	HFL	SCRIPT A1	
		KEYEK=1 TMUD=0. DTMUD=0.2D0 TMAX=2.0D0 DT=2.5D-3 GAMA=1.54D0 KEYMON=1 STAB=0.6D0	HFL0145 HFL0146 HFL0147 HFL0148 HFL0149 HFL0150 HFL0151 HFL0152
	С	RATE=1.5D0 GODELX=16. GODELY=20. IVERSA=100 UMIN=0. UMAX= 3.D0 PMIN=0. PMAX=1.D-3 ROMIN=0. ROMAX=1.D-3 SMIN=0. SMAX=PMAX/ROMAX**GAMA	HFL0153 HFL0154 HFL0155 HFL0156 HFL0157 HFL0158 HFL0159 HFL0160 HFL0161 HFL0163 HFL0164
	С	READ IN	HFL0165 HFL0166
	C	PRINT IN	HFL0167 HFL0168
	10	GG=2.*GAMA/(GAMA-1.) NG=GG CONTINUE MU2=(GAMA-1.)/(GAMA+1.) G1=GAMA-1. G2=1MU2 G3=2./(3.*GAMA-1.) G4=(GAMA+1.)/2. G5=0.5*(3.*GAMA-1.)/(GAMA+1.) G6=(GAMA+1.)/(2.*GAMA) G7=2./(GAMA-1.) G8=(GAMA-1.)/(2.*GAMA) G9=(GAMA+1.)/(4.*GAMA) G10=1./GAMA G11=(GAMA+1.)/4.	HFL0169 HFL0170 HFL0172 HFL0173 HFL0173 HFL0174 HFL0175 HFL0176 HFL0177 HFL0178 HFL0181 HFL0181 HFL0183 HFL0183 HFL0184
	C C C DAT C UNI C FH	G12-GAMA/(GAMA-1.) G13=0.5*(GAMA-3.)/(GAMA+1.) G14=0.5*(3.*GAMA-5.)/(GAMA+1.) G17=GAMA+1. GODELX=GODELX/2.54 GODELY=GODELY/2.54 CALL NAMPLT(IVERSA) CALL PLOT(0.,0.5,-3) A FOR DIFFUSER ENTRY CONDITIONS. TEST III/2, REF.(M-1). TS ARE IN M,K,MILISEC. 2 IS THE DIFFUSER ENTRY MOLAR FRACTION OF H ATOMS. FH2=0.091D0 U2=2.3D0 AMDOT=1.499D-5	HFL0185 HFL0186 HFL0188 HFL0188 HFL0190 HFL0191 HFL0193 HFL0193 HFL0195 HFL0196 HFL0198 HFL0198 HFL0198 HFL0198
		A2=1.D0*7.D0*0.0254**2 R02=AMDOT/(A2*U2) TEMP0=1400.D0 W2=7.27D0 ARW=8.31441D-3/W2 DELTAQ=435.783/2.D0 QDET=FH2*DELTAQ/W2 AA=U2/DSQRT(GAMA*ARW*TEMP0) RATE=1.4D0*1.D7*FH2/W2**2 RATE=RATE*1.D2 EM2=AA/DSQRT(1AA**2/G7) GOREM=(1.D0+EM2**2/G7) TRATIO=2.D0*(GAMA+1.D0)*EM2**2*GOREM/(1.D0+GAMA*EM2**2)**2 HH0=GAMA*ARW*TEMP0/(GAMA-1.D0) HH1=HH0/TRATIO CH0KE=QDET/(HH1-HH0) TEMP2=TEMP0/GOREM	HFL0200 HFL0201 HFL0202 HFL0203 HFL0204 HFL0205 HFL0206 HFL0207 HFL0208 HFL0209 HFL0210 HFL0211 HFL0212 HFL0213 HFL0214 HFL0215

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<pre>P2=ARW*R02*TEMP2 RATIO=2.5D0/0.5D0 EMOUT=EM2*RATIO**((GAMA-1.D0)/2.D0) D0 250 I=1,100 EMOUT=EMOUT GOREM=RATIO*EMOUT*(1.D0+0.5D0*(GAMA-1.D0)*EM2**2)**(0.5D0/MU2)/EM2 GOREM=GOREM**(2.D0*MU2) EMOUT=DSQRT((2.D0/(GAMA-1.D0))*(GOREM-1.D0)) DM=DABS(EMOUT-EMOUT1) IF(DM.LT.1.D-9) GO TO 251 CONTINUE CALL SOF(251) 251 CONTINUE PRINT 201 201 FORMAT(/1X,'DIFFUSER ENTRY DATA') PRINT 202,U2,P2,R02,FH2 202 FORMAT(/1X,'U2,P2,R02,FH2=',4D16.5) PRINT 203,AMDOT,W2,TEMP0,TEMP2,EM2=',5D16.5) PRINT 204,RATE,QDET,HH0,HH1,CH0KE=',5D16.5/) PRINT 205,RATIO,EMOUT 205 FORMAT(/1X,'EXIT AREA RATIO AND MACH NUMBER RATIO,EMOUT=',2D16.5) RETURN END</pre>	HFL0217 HFL0218 HFL0220 HFL0220 HFL0222 HFL0222 HFL0223 HFL0225 HFL0226 HFL0226 HFL0227 HFL0228 HFL0230 HFL0230 HFL0231 HFL0232 HFL0233 HFL0235 HFL0235 HFL0236 HFL0237 HFL0238 HFL0238 HFL0239 HFL02240 HFL0240
1 (L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN, 2 US,PS,UIDOT,PIDOT, * FIMZ,ZMDOT,	HFL0242 HFL0243 HFL0244 HFL0245
<pre>3 TENA,FIRO,FIM,FIE,GIP,VOL,Z,DZ) IMPLICIT REAL*8(A-H,O-Z,\$) DIMENSION X(L),U(L),P(L),RO(L),G(L),E(L),DU(L),DP(L),DRO(L), 1 DG(L),DXSI(L),MIN(L), 2 US(L),PS(L),UIDOT(L),PIDOT(L) 3 ,TENA(L),FIRO(L),FIE(L) 6 OTP(L) VO(L) Z(L) Z(L)</pre>	HFL0246 HFL0247 HFL0248 HFL0249 HFL0250 HFL0250
<pre>5 , FIMZ(L),ZMDOT(L) 5 , FIMZ(L),ZMDOT(L) COMMON /AB/A(50) COMMON /GAM/GAMA,NG,MU2,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11</pre>	HFL0252 HFL0253 HFL0255 HFL0256
REAL*8 NG REAL*8 MU2 EQUIVALENCE (LL,A(2)) EQUIVALENCE (LAGEUL,A(14)) EQUIVALENCE (UGAL,A(15)) EQUIVALENCE (STAB,A(18)),(DTBA,A(19)),(DTKOD,A(20)),(KDT,A(21)) COMMON/DETO/QDET,TC,RATE,PCJDET,RCJDET,UCJDET,DCJDET,PODET,ROODET COMMON / DRAW/GODELX,GODELY,UMIN,UMAX,PMIN,PMAX,ROMIN,ROMAX XMIN,XMAY_SMIN,SMAY_IVERSA	HFL0257 HFL0258 HFL0259 HFL0260 HFL0261 HFL0262 HFL0263 HFL0264 HFL0265
C*************************************	<pre>#HFL0266 HFL0267 HFL0268 HFL0269 HFL0270 HFL0271 HFL0272 HFL0273</pre>
RH01=0.125 RH01=4. UGAL=0. U0=1.08D0 U1=0. U0=U0-UGAL U1=U1-UGAL UMIN=UMIN-UGAL	HFL0274 HFL0275 HFL0276 HFL0277 HFL0278 HFL0279 HFL0280 HFL0281
UMAX=UMAX-UGAL X0=0.625D0 X1=3.125D0 XMIN=X0 XMAX=X1 DX=(X1-X0)/(L-2.) D0 1 I=2,L	HFL0282 HFL0283 HFL0284 HFL0285 HFL0286 HFL0287 HFL0288

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	1	X(I)=X0+(CONTINUE X(L)=X1	(I-2.)*DX	HFL0289 HFL0290 HFL0291
		XD=1.D10	11	HFL0292
		U(I)=U0/>		HFL0294
		P(I)=P0 R0(I)=RH0	00	HFL0295 HFL0296
		Z(I)=0.	-YD LT -1 D-8) CO TO 21	HFL0297
		U(I)=U1		HFL0299
		P(I)=P1 RO(I)=RHO	1	HFL0300 HFL0301
	21	Z(I)=1.DC		HFL0302
	21	GO TO (3)	1,32), LAGEUL	HFL0304
	31	CONTINUE F(I)=P(I))/((GAMA-1.)*RO(T))+0.5*U(T)**2+7(T)*0DFT	HFL0305 HFL0306
	70	GO TO 30		HFL0307
	32	E(I)=P(I))/(GAMA-1.)+0.5*R0(I)*U(I)**2+Z(I)*R0(I)*QDET	HFL0308 HFL0309
	30	CONTINUE	ΑΤ(GAMA¥Ρ(Ι)¥RO(Ι))	HFL0310
	2	CONTINUE		HFL0312
		DU 3 1=2, DXSI(I)=(,LL (X(I+1)-X(I))*RO(I)	HFL0313 HFL0314
		TENA(I)=F	RO(I)*U(I)	HFL0315
	3	CONTINUE		HFL0317
		RETURN		HFL0318 HFL0319
		DOUBLE PR	RECISION FUNCTION RATIO(X)	HFL0320
		IF(X.LE.]	L.D-8)RATIO=0.	HFL0322
		IF(X.LE.] RATIO=1 I	1.D-8)RETURN	HFL0323 HFL0324
		RETURN		HFL0325
-		DOUBLE PR	RECISION FUNCTION CROSS(X)	HFL0327
		IMPLICIT CROSS=X	REAL*8(A-H,0-Z,\$)	HFL0328 HFL0329
		RETURN		HFL0330
		SUBROUTIN	NE CYCEUL	HFL0331
		1	(L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN, US,PS,UIDOT,PIDOT,	HFL0333
		×	FIMZ, ZMDOT,	HFL0335
		3 IMPLICIT	TENA,FIRU,FIM,FIE,GIP,VOL,Z,DZ) REAL*8(A-H,O-Z,\$)	HFL0336 HFL0337
		DIMENSION	<pre>N X(L),U(L),P(L),RO(L),G(L),E(L),DU(L),DP(L),DRO(L), DG(L) DYST(L) MIN(L)</pre>	HFL0338
		2	US(L), PS(L), UIDOT(L), PIDOT(L)	HFL0340
		3 4	,TENA(L),FIRO(L),FIM(L),FIE(L) ,GIP(L),VOL(L),Z(L),DZ(L)	HFL0341 HFL0342
			, FIMZ(L), ZMDOT(L)	HFL0343
		EQUIVALEN	NCE (LL,A(2)),(T,A(3)),(DT,A(4)),(COLELA,A(13))	HFL0345
		EQUIVALEN	NCE (KEYEK,A(16)) NCE (STAB.A(18)).(DTBA.A(19)).(DTKOD.A(20)).(KDT.A(21))	HFL0346 HFL0347
		COMMON /C	GAM/GAMA, NG, MU2, G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11	HFL0348
		REAL¥8 NO	,612,613,614,615,616,617,618,619,620 3	HFL0350
		REAL¥8 MU	U2 INIZAMINI, FINI, FRINI, FRINI, IFNINI	HFL0351 HFL0352
		COMMON /	AZOV/ISAFA, NORIMN, USAF, PSAF, ROSAF, GSAF, ESAF, DPSAF	HFL0353
		LOGICAL N	,DXSIL,DXSIR NORIMN	HFL0354 HFL0355
		COMMON /S	STEP0/UL,PL,ROL,GL,UR,PR,ROR,GR,USTAR,PSTAR,	HFL0356
		2	CL, CR, CSTARL, CSTARL, USIAKK, WL, WK,	HFL0358
		3 LOGICAL H	,ZL,ZR,ZSTARL,ZSTARR,NFLUX,HELEML,HELEMR HELEML,HELEMR	HFL0359 HFL0360

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COMMON /STEP1/DUIDT,DPIDT,DGIDTL,DGIDTR,DRIDTL,DRIDTR 2 ,ASTARL,ASTARR	HFL0361 HFL0362
3 ,RAT,SH COMMON /GRADS/DUDXIL,DPDXIL,DGDXIL,DRDXIL,	HFL0363 HFL0364
1 DUDXIR, DPDXIR, DGDXIR, DRDXIR COMMON /FI/FIH1, FIH2, FIH3, UXN, PXN, GXN, ROXN	HFL0365 HFL0366
1 ,GIH 2 ,FIH4,ZMDOTL,ZMDOTR	HFL0367 HFL0368
COMMON/DETO/QDET,TC,RATE,PCJDET,RCJDET,UCJDET,DCJDET,P0DET,R00 CDATA KOTZ/7777777778/	DET HFL0369 HFL0370
C*************************************	<pre></pre>
DT2=DT/2. D0 3 I=1,L	HFL 0 37 3 HFL 0 37 4
C MINO=MIN(I).AND.KOTZ C MIN(I)=SHIFT(MINO,30)	HFL0375 HFL0376
3 CONTINUE UXN=0.	HFL 0 37 7 HFL 0 37 8
PXN=0. GXN=0.	HFL0379 HFL0380
ZN=0. R0XN=0.	HFL0381 HFL0382
DO 1 I=2,L IM=I-1	HFL0383 HFL0384
	HFL0385 HFL0386
GXNM=GXN ROXNM=ROXN	HFL0387 HFL0388
ZNM=ZN $UI = U(TM) + 0.5 \times DU(TM)$	HFL0389 HFL0390
$PL = P(IM) + 0.5 \times DP(IM)$ $RDI = RD(IM) + 0.5 \times DRO(IM)$	HFL0391 HFL0392
$GL = G(IM) + 0.5 \times DG(IM)$ $CL = GL \times RDL$	HFL 0393 HFL 0394
$ZL = Z(IM) + 0.5 \times DZ(IM)$ $UR = U(I) - 0.5 \times DU(I)$	HFL0395 HFL0396
$PR=P(I)=0.5 \times DP(I)$ $GR=G(I)=0.5 \times DG(I)$	HFL0397 HFL0398
$ROR = RO(I) + 0.5 \times DRO(I)$	HFL0399
$ZR=Z(I)-0.5 \times DZ(I)$	HFL0401 HFL0402
DUDXIL=DU(IM)/DXSI(IM)	HFL0403 HFL0404
DGDXIL=DG(IM)/DXSI(IM) DGDXIL=DG(IM)/DXSI(IM)	HFL0405
	HFL0407
	HFL0409
SH=CROSS(X(I)) SH=CROSS(X(I))	HFL0411
CALL MAGA(L), MIN)	HFL0413
	HFL0415
	HFL0417
CALL FLUXE2(L,I,MIN) CALL FLUXE2(L,I,MIN)	HFL0419
FIRU(I) = FIRI	HFL0421
	HFL0423
	HFL0425
DF(IM) = PXN - PXNM $DG(IM) = GXN - GXNM$	HFL0427
DRO(IM)=ROXN-RUXNM CONTINUE	HFL0429
AMTOT=0. ETOT=0.	HFL0431
EKTOT=0.	NFL0432

EPTOT=0.	HFL0433
FII=FIRO(2)	HFL0434
FI2=FIM (2)	HFL0436
F14=F1MZ(2) GI2=GIP(2)	HEL0437
SH=CROSS(X(2))	HFL0439
DO 2 I=2,LL IP=I+1	HFL0440
FIM1=FI1	HFL0442
FIM2=FI2	HFL0443
GIM2=GI2	HFL0444
SHM=SH	HFL0446
GIZ=GIP(IP) SH=CROSS(X(IP))	HFL0447
DVOL=VOL(I)	HFL0449
FII=FIRO(IP)	HFL0450
FI4=FIMZ(IP)	HFL0451
ZKODM=Z(I)*RO(I)	HFL0453
RO(I)=RO(I)-DT/DVOL*(SH*FI1-SHM*FIM1)	HFL0454
TENA(I)=TENA(I)-DT/DVOL*(SH*FI2-SHM*FIM2)-DT/DX*(GI2-GIM2)	HFL0456
U(I)=TENA(I)/RU(I) IE(QDET_EQ.0.) GO_TO_2	HFL0457 HFL0458
Z(I)=(ZKODM-(DT/DVOL)*(SH*FI4-SHM*FIM4))/RO(I)	HFL0459
DZZI=Z(I)-1.DO	HFL0460
IF(DZZ1.LT.0.) GO TO 7352	HFL0462
Z(I)=1.D0	HFL0463
7352 CONTINUE	HFLU464 HFL0465
IF(Z(I).GT.0.) GO TO 7353	HFL0466
Z(1)=0. IE(DABS(Z(I)) II 0 2D0) GO IO 7350	HFL0467
7353 CONTINUE	HFL0469
PRINT 7351,I,Z(I),P(I),R0(I),E(I),U(I),ZMDOT(I)	HFL0470
CALL SOF(7350)	HFL0472
7350 CONTINUE	HFL0473
2 CONTINUE	HFL0475
IF(COLELA.EQ.0.) GO TO 201	HFL0476
CALL DCOLECL,X,O,DO,MIN,I) CALL DCOLE(L,X,RO,DRO,MIN,4)	HFL04//
201 CONTINUE	HFL0479
CALL BDOK1(L,X,U ,DU ,MIN,1)	HFL0480
FI3=FIE (2)	HFL0482
SH=CROSS(X(2))	HFL0483
IP=I+1	HFL0485
SHM=SH	HFL0486
DVOL=VOL(I)	HFL0487
FIM3=FI3	HFL0489
FI3=FIE (IP) DY=Y(IP)-Y(I)	HFL0490
E(I)=E(I)-DT/DVOL*(SH*FI3-SHM*FIM3)	HFL0492
	HFL0493
C	HFL0495
ROAV=RO(I)	HFL0496
EP=E(I)-0.5*ROAV*UAV**2	HFL0498
IF (QDET.EQ.0.) GO TO 64	HFL0499
DZZ=-RATE*DT*(RO(I)*Z(I))**2	HFL0501
Z(I) = Z(I) + DZZ	HFL0502
IF(Z(I),LT.0.01) Z(I)=0.	HFL0504

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		FP=FP-7(I)*PO(I)*ODET	
	64	CONTINUE	HFL0506
	61	GO TO (61,62), KEYEK	HFL0507
	01	GO TO 60	HFLUSU8 HFL0509
	62	CONTINUE DEK-CROAVXDUCTXXX212, XDROCTXXDUCTXXUAVX (CC	HFL0510
		EP=EP-DEK	HFL0511 HFL0512
	()	GO TO 60	HFL0513
	60	IF(EP.LE.0.) GO TO 7001	HFL0514 HFL0515
		P(I)=G1×EP	HFL0516
		DM=RO(I)+DX DM=RO(I)+DX	HFL0517
		DXSI(I)=DM	HFL0519
		DM=RO(I)*DVOL FTOT=FTOT+F(I)*DVOL	HFL0520
		EPTOT=EPTOT+EP*DVOL	HFL0522
		AMTOT=AMTOT+DM	HFL0523
		EPTOT=EPTOT+EP*DX	HFL0524 HFL0525
		TENTOT=TENTOT+DX*TENA(I)	HFL0526
		UPC=DABS(U(I))+G(I)/RO(I) DTI=STAB¥DX/UPC	HFL0527
		IF(DTI.GT.DTBA) GO TO 69	HFL0529
		DTBA=DTI	HFL0530
	69	CONTINUE	HFLU531 HFL0532
	6	CONTINUE	HFL0533
		$\begin{array}{c} CALL DCOLE(L,X,Z,DZ,MIN,5) \\ TE(COLELA ER O D O O TO COL O I \\ O O I O O O I O O O I \\ O O O I O O O O O O O O$	HFL0534
		CALL DCOLE(L,X,P,DP,MIN,2)	HFL0536
	601	CALL DCOLE(L,X,G,DG,MIN,3)	HFL0537
	501	CALL BDOK1(L,X,P,DP,MIN,2)	HFL0539
		CALL BDOK1(L,X,G,DG,MIN,3)	HFL0540
		CALL BDOKI(L,X,Z,DZ,MIN,5) FKTOT=FTOT-FPTOT	HFL0541 HFL0542
		RETURN	HFL0543
	7001	CONTINUE PRINT 7101 I ROAV HAV DRO(I) DH(I) E(I) DEK ER KEYEK	HFL0544
	7101	FORMAT(//1X, 'FROM CYCEUL. NEGATIVE EP. IN CELL I=', I6//	HFL0546
	1	1X, 'ROAV, UAV, DRO(I), DU(I)=', 4D18.8//	HFL0547
	4	CALL SOF(7001)	HFL0548 HFL0549
		RETURN	HFL0550
<u> </u>		SUBROUTINE SAFAE	HFL0551 HFL0552
	1	(L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXSI,MIN,	HFL0553
	2	US,PS,UIDOT,PIDOT, EIMZ.ZMDOT.	HFL0554 HFL0555
	3	TENA, FIRO, FIM, FIE, GIP, VOL, Z, DZ)	HFL0556
		IMPLICIT REAL*8(A-H,O-Z,\$)	HFL0557
	1	DIMENSION X(L), U(L), P(L), RU(L), U(L), D(L), D	HFL0559
	2	US(L), PS(L), UIDOT(L), PIDOT(L)	HFL0560
	ŝ	, IENA(L), FIRU(L), FIM(L), FIE(L) GIP(L), VOL(L), Z(L), DZ(L)	HFL0561 HFL0562
	5	,FIMZ(L),ZMDOT(L)	HFL0563
		COMMON ZABZA(50) FOUTVALENCE (11, A(2)), (T, A(3)), (DT, A(4)), (NCYC, A(12))	HFL0564 HFL0565
		COMMON / GAM/ GAMA, NG, MU2, G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11	HFL0566
	1	,G12,G13,G14,G15,G16,G17,G18,G19,G20	HFL0567
		REALX8 MU2	HFL0569
		COMMON/DETO/QDET,TC,RATE,PCJDET,RCJDET,UCJDET,DCJDET,PODET,ROODET	HFL0570
C	***××	COMMON/DIFFUS/U2,P2,R02,ARW /************************************	HFL0571 HFL0572
C	~~~~	TN=T	HFL0573
C	TAIF		HFL0574
C	TNF	LUM D.C. AT 1-2	HFL0576

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U(1) = U2
                                                                               HFL 0577
      P(1)=P2
                                                                               HE1 0578
      RO(1)=RO2
                                                                               HFL 0579
      G(1) = DSORT(GAMA \times P(1) \times RO(1))
                                                                               HFL 0580
      Z(1)=1.D0
                                                                               HFL 0581
      DU(1) = 0.
                                                                               HEL 0582
      DP(1) = 0.
                                                                               HFL0583
      DG(1)=0.
DRO(1)=0
                                                                               HFL0584
                                                                               HFL0585
                                                                               HFL 0586
      DXSI(1)=DXSI(2)
                                                                               HFL 0587
C
C
C
                                                                               HFL0588
   OUTFLOW B.C. AT I=L
                                                                               HFL0589
                                                                               HFL0590
      U(L)=U(LL)
                                                                               HFL0591
      P(L)=P(LL)
      RO(L)=RO(LL)
                                                                               HFL0592
                                                                               HFL0593
      G(L)=DSQRT(GAMA*P(L)*RO(L))
                                                                               HFL0594
      DU(L)=0.
      DP(L)=0.
                                                                               HFL 0595
      DG(L)=0.
                                                                               HFL0596
      DRO(L)=0
                                                                               HFL0597
      DXSI(L)=DXSI(LL)
                                                                               HFL 0598
                                                                               HFL 0599
С
      RETURN
                                                                               HFL0600
                                                                               HEL0601
      END
      SUBROUTINE BDOK1(L,X,V,DV,MIN,NV)
                                                                               HFL0602
      IMPLICIT REAL ×8(A-H, 0-Z, $)
                                                                               HFL0603
      DIMENSION X(L),V(L),DV(L),MIN(L)
                                                                               HFL0604
      COMMON /AB/A(50)
                                                                               HFL0605
      EQUIVALENCE (LL,A(2)),(KEYMON,A(11))
                                                                               HFL0606
      COMMON / DRAW/GODELX, GODELY, UMIN, UMAX, PMIN, PMAX, ROMIN, ROMAX
                                                                               HFL0607
      ,XMIN,XMAX,SMIN,SMAX,IVERSA
COMMON /MONIT/NC14(4),CASEAV(4),NF16(6),
                                                                               HFL0608
     1
                                                                               HFL0609
                        NMONU(4), NMONP(4), NMONG(4), NMONRO(4), NMONZ(4)
                                                                               HFL0610
     1
      DIMENSION NMONV(4,5)
                                                                               HFL0611
      EQUIVALENCE (NMONV(1,1),NMONU(1))
                                                                               HFL0612
      DIMENSION NAMEV(5)
С
                                                                               HFL0613
č
      DATA NAMEV/1HU,1HP,1HG,2HRO,1HZ/
                                                                               HFL0614
      DATA EPS/1.D-15/
                                                                               HFL0615
С
      NV = 0
                                                                               HFL0617
Č
      DO 10 N=1,5
                                                                               HFL0618
С
      IF (NAME.EQ.NAMEV(N))NV=N
                                                                               HFL0619
C10
      CONTINUE
                                                                               HFL0620
      GO TO (1,2,3,4,5), NV
AMIDA=(UMAX-UMIN)**2
                                                                               HFL0621
 1
                                                                               HFL0622
      GO TO 9
                                                                               HFL0623
 2
      AMIDA=(PMAX-PMIN) **2
                                                                               HFL0624
      GO TO 9
                                                                               HFL0625
 3
                                                                               HFL0626
      AMIDA=((UMAX-UMIN)*(ROMAX-ROMIN))**2
      GO TO 9
                                                                               HFL0627
 4
      AMIDA=(ROMAX-ROMIN)**2
                                                                               HFL0628
      GO TO 9
                                                                               HFL0629
      AMIDA=1.DO
                                                                               HFL0630
 5
      GO TO 9
                                                                               HFL0631
 9
      CONTINUE
                                                                               HFL0632
                                                                               HFL0633
      AMIDA=AMIDA×EPS××2
                                                                               HFL0634
      AMIDA=EPS
                                                                               HFL0635
      DO 29 I=2,LL
      ICAT=0
                                                                               HFL0636
                                                                               HFL0637
      VLEFT=V(I)-0.5D0×DV(I)
      VRIGHT=V(I)+0.5D0×DV(I)
                                                                               HFL0638
      VM=V(I-1)
                                                                               HFL0639
      VP=V(I+1)
                                                                               HFL0640
      SIGN=(VP-V(I))*(V(I)-VM)
                                                                               HFL0641
                                                                               HFL0642
      IF(SIGN.GT.-AMIDA) GO TO 22
                                                                               HFL 0643
  21
      DV(I)=0.
      ICAT=1
                                                                               HFL0644
      GO TO 20
                                                                               HFL0645
  22
      CONTINUE
                                                                               HFL0646
                                                                               HFL0647
      SIGN=(VP-VM)*DV(I)
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HFL0648

IF(SIGN.GT.-AMIDA) GO TO 24

	23	DV(I)=0.5D0*(VP-VM)	HE1 0669	
	2.0	VLEFT=V(I)-0.5D0×DV(I)	HFL0650	
		VRIGHT=V(I)+0.5D0×DV(I)	HFL0651	
	24		HFL0652	
	24	TERSION GT -AMIDAL GO TO 24	HFL0653	
	25	VIFFT=VM	HEL0654	
		VRIGHT=2.DO*V(I)-VLEFT	HFL0656	
		DV(I)=VRIGHT-VLEFT	HFL0657	
	2(HFL0658	
	26	$\frac{1}{10} = \frac{1}{10} $	HFLU659	
	27	VRIGHT=VP	HFL0661	
		VLEFT=2.D0×V(I)-VRIGHT	HFL0662	
		DV(I)=VRIGHT-VLEFT	HFL0663	
	20	ICAI=5 IE(DARS(DV(T))) IE 0 ED0XDARS(VD-VM)) CO TO 71	HFL0664	
	30	DV(I)=0.5D0*(VP-VM)	HELOGGS	
	00	ICAT=4	HFL0667	
	31	CONTINUE	HFL0668	
	20	CONTINUE	HFL0669	
		TF (DV(1)**2.01.AMIDA) 00 10 40 DV(T)=0	HFL0670	
	40	CONTINUE	HFL0672	
	С	IF (ICAT.GT.0) NMONV(ICAT,NV)=NMONV(ICAT,NV)+1	HFL0673	
	C	IBYTE0=5	HFL0674	
	20	MIN(I)=MIN(I).UR.SHIFI(ICAI,(NV+IBYIEU=2)*3)	HFLU6/5	
	27	RETURN	HFL0677	
_		END	HFL0678	
		SUBROUTINE DCOLE(L,X,V,DV,MIN,NV)	HFL0679	
		IMPLICIT REAL*8(A=H,U=Z,S) DIMENSION Y(L) V(L) MIN(L)	HFL0680	
		COMMON /AB/A(50)	HFL0682	
		EQUIVALENCE (LL,A(2))	HFL0683	
	C****	*************************************	HFL0684	
		IM=I-1	HFL0686	
		IP=I+1	HFL0687	
		$DV(I)=0.5 \times (V(IP)-V(IM))$	HFL0688	
	1		HFL0689	
_			HFL0691	
		SUBROUTINE PRINT	HFL0692	
	ļ	(L,X,U,P,RO,G,E,DU,DP,DRO,DG,DXS1,MIN,	HFL0693	
	4	FIMZ.ZMDOT.	HFL0695	
		TENA, FIRO, FIM, FIE, GIP, VOL, Z, DZ)	HFL0696	
		IMPLICIT REAL*8(A-H,O-Z,\$)	HFL0697	
		DIMENSION X(L),U(L),P(L),RO(L),G(L),E(L),DU(L),DP(L),DRO(L),	HFL0698	
			HFL0700	
		TENA(L), FIRO(L), FIM(L), FIE(L)	HFL0701	
	ć	,GIP(L),VOL(L),Z(L),DZ(L)	HFL0702	
	-	,FIMZ(L),ZMDOT(L)	HFL0703	
		COMMON / OI/AMIOI, EIUI, EKIUI, EPIUI, IENIUI	HFL0704 HFL0705	
		RSTARL RSTARR.GSTARL.GSTARR.WL.WR.	HFL0706	
		CL, CR, CSTARL, CSTARR, UW(6)	HFL0707	
		, ZL, ZR, ZSTARL, ZSTARR, NFLUX, HELEML, HELEMR	HFL0708	
		LOGICAL HELEML, HELEMR	HFL0709	
		EQUITION ($AD/A(50)$) EQUITVALENCE (11,A(2)),(T,A(3)),(NCYC,A(12)),(DT,A(4))	HFL0711	
		EQUIVALENCE (UGAL, A(15))	HFL0712	
		COMMON/DETO/QDET,TC,RATE,PCJDET,RCJDET,UCJDET,DCJDET,PODET,ROODET	HFL0713	
		COMMON/DIFFUS/U2, P2, R02, ARW	HFLU/14 HFL0715	
		CUMMUN /GAM/GAMA,NG,MUZ,GI,GZ,G3,G4,G5,G6,G7,G8,G79,G10,G11 G12 G13 G14 G15 G14 G17 G18 G19 G20	HELOTIS	
		REAL*8 NG	HFL0717	
		REAL*8 MU2	HFL0718	
		COMMON /MONIT/NC14(4), CASEAV(4), NF16(6),	HFL0719	
		NMUNU(4),NMUNP(4),NMUNG(4),NMUNRU(4),NMUNZ(4)	nFL0/20	

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DIMENSION CASAV1(4) HFL0721 LOGICAL FULLPR HFL0722 COMMON /PRNT/ROX,PX,UX,ZX HFL0723 FULLPR=.TRUE. HFL 07 25 PRINT HFL0726 1 1 FORMAT(1H1) HFL0727 PRINT 2, T, DT, NCYC HFL0728 FORMAT(1X,10X, 'RESULTS AT T=',D11.5,5X, 'DT=',D11.5,5X, 'NCYC=', 2 HFL0729 15//) 1 HFL0730 PRINT 3, AMTOT, ETOT, EKTOT, EPTOT, TENTOT HFL0731 FORMAT(1X, 'AMTOT=', D20.14,2X, 'ETOT, EKTOT, EPTOT=', 3D22.14/ 1X, 'TENTOT=', D21.14//) HFL0732 3 1 HFL 07 33 , 1 FORMAT(1X, ' . 4 I',' . Ρ 1 HFL0734 X 11 , , ;; ٢, . 1,1 1 R0 G Ζ HFL0735 ۲, ۲, 2 DP 1 DRO DU 1 HFL 07 36 1 DZ') 3 DG 1 HFL0737 4 , 1 44 FORMAT(1X, 1 ÜS 1 1 PS 1 HFL0738 1,1 , , ۲, Ŧ . ۲, 1 1 ZMDOT FIMZ AMDOT HFL0739 ۲, ۲, . 1 HFL 0740 2 . AMDOTN TEMP ENTALP 1) 1,1 3 AMACH ENTRO HFL0741 5 FORMAT(1X) HFL 07 42 IF (UGAL.NE.0.) PRINT 6, UGAL HFL0743 FORMAT(/11X, 'INITIAL VELOCITY CORRESPONDS TO UGAL=', D15.6/) HFL0744 6 DO 10 I=1,L IF (MOD(I,10).NE.1) GO TO 11 HFL0745 HFL0746 HFL0747 PRINT 5 PRINT 4 HFL0748 PRINT 44 HFL0749 PRINT 5 HFL0750 11 CONTINUE HFL0751 HFL0752 PRINT 12,I,X(I),U(I),P(I),R0(I),G(I),Z(I),DU(I),DP(I),DR0(I), DG(I), DZ(I) HFL0753 1 HFL0754 12 FORMAT(1X, I3, 6D12.5, 5D11.4) ENTRO=P(I)/RO(I)**GAMA HFL0755 IF(.NOT.FULLPR) GO TO 131 HFL0756 IF(I.EQ.1) GO TO 131 HFL0757 IM=I-1 HFL0758 $UL = U(IM) + 0.5 \times DU(IM)$ HFL 07 59 PL=P(IM)+0.5*DP(IM) HFL0760 ROL=RO(IM)+0.5*DRO(IM) HFL0761 HFL0762 $GL=G(IM)+0.5 \times DG(IM)$ CL=GL/ROL HFL0763 $ZL = Z(IM) + 0.5 \times DZ(IM)$ HFL0764 $UR=U(I)-0.5 \times DU(I)$ HFL0765 PR=P(I)-0.5*DP(I) HFL0766 GR=G(I)=0.5*DG(I)HFL0767 ROR=RO(I)-0.5*DRO(I) HFL0768 CR=GR/ROR HFL0769 ZR=Z(I)=0.5*DZ(I)HFL0770 CALL RIEMAN(L, I, MIN) HFL0771 HFL0772 CALL FLUXE1(L, I, MIN) XI = X(I)HFL0773 HFL0774 IF(I.EQ.L) GO TO 222 UX=U(I) HFL0775 PX=P(I) HFL0776 ROX=RO(I) HFL0777 ZX=Z(I) HFL0778 IP=I+1HFL0779 XI=0.5D0*(X(I)+X(IP)) HFL0780 HFL0781 222 CONTINUE HFL0782 AMACH=UX/DSQRT(GAMA*PX/ROX) AMDOT=ROX*UX*CROSS(XI) HFL0783 HFL0784 IF(I.EQ.2)AMDOTO=AMDOT HFL0785 AMDOTN=AMDOT/AMDOT0 HFL0786 ENTALP=(GAMA/(GAMA-1.D0))*PX/ROX+0.5D0*UX**2 TEMP=PX/(ROX*ARW) HFL 0787 PRINT 13, US(I), PS(I), HFL0788 ZMDOT(I), FIMZ(I), AMDOT, AMDOTN, TEMP, ENTALP, AMACH, ENTRO HFL0789 1 HFL0790 13 FORMAT(4X,12X,5D12.5,6D11.4) CONTINUE HFL0791 131 HFL0792 10 CONTINUE

C JC C C C C C C C C C C C C C C C C C C	DB STATISTICS DO 40 I=1,4 CASAV1(I)=0. IF (NCl4(I).NE.0) CASAV1(I)=CASEAV(I)/NCl4(I) CONTINUE PRINT 30 FORMAT(///1X,10(1H*),3X,'JOB STATISTICS',3X,10(1H*)//) PRINT 31,(NCl4(I),I=1,4) FORMAT(1X,'NO. OF VARIOUS CASES IN RIEMAN SOLVER NCl4(NCASE)=', 1 4110) PRINT 301, (CASAV1(I),I=1,4) FORMAT(/1X,'AVERAGE NUMBER OF ITERATIONS IN RIEMAN SOLVER', 1 1X,' CASAV1(NCASE)=',4(F6.2,4X)) PRINT 32,(NF16(I),I=1,6) FORMAT(/1X,'NO. OF VARIOUS FLUX CASES NF16(NFLUX)=',6I10) ICAT0=4 PRINT 33,(NMONU(I),I=1,ICAT0),(NMONP(I),I=1,ICAT0), 1 (NMONG(I),I=1,ICAT0),(NMONRO(I),I=1,ICAT0), FORMAT(/1X,'NO. OF MONOTONICITY INTERVENTIONS FOR EACH VAR.', 1 1X,'IN EACH CATEGORY.'/ 1 1X,'NMONU (ICAT)=',4I10/ 1 1X,'NMONG (ICAT)=',4I10/ 1 1X,'NMONRO(ICAT)=',4I10/ 1 1X,'NMONRO(ICAT)=',4I10/ 1 1X,'NMONRO(ICAT)=',4I10/ 1 1X,'NMONRO(ICAT)=',4I10/ 1 1X,'NMONRO(ICAT)=',4I10/ 1 1X,'NMONRO(ICAT)=',4I10/) RETURN FND	HFL0793 HFL0794 HFL0795 HFL0797 HFL0797 HFL0798 HFL0800 HFL0801 HFL0801 HFL0803 HFL0804 HFL0805 HFL0805 HFL0808 HFL0808 HFL0810 HFL0810 HFL0811 HFL0813 HFL0814 HFL0815 HFL0816 HFL0817 HFL0817 HFL0818
	SUBROUTINE SOF(ISTOP)	HFL0819
	IMPLICIT REAL*8(A-H,O-Z,\$) PRINT 1. ISTOP	HFL0820 HFL0821
1	FORMAT(1x, 3H***, 3X, 'SOF', I6, 3X, 3H***/)	HFL0822
	YY=DSQRT(XX)	HFL0823 HFL0824
С	CALL SYSTEM(51,16H SUBROUTINE TREE)	HFL0825
		HFL0827
	SUBROUTINE RIEMAN(L,I,MIN)	HFL0828 HFL0829
	DIMENSION MIN(L)	HFL0830
	COMMON /STEPO/UL,PL,ROL,GL,UR,PR,ROR,GR,USTAR,PSTAR,	HFL0831
	2 CL,CR,CSTARL,CSTARR,UW(6)	HFL0833
	3, ZL, ZR, ZSTARL, ZSTARR, NFLUX, HELEML, HELEMR	HFL0834
	COMMON /STEP1/DUIDT, DPIDT, DGIDTL, DGIDTR, DRIDTL, DRIDTR	HFL0836
	2 , ASTARL, ASTARR	HFL0837
	COMMON /DRAW/GODELX,GODELY,UMIN,UMAX,PMIN,PMAX,ROMIN,ROMAX	HFL0839
	1 ,XMIN,XMAX,SMIN,SMAX,IVERSA	HFL0840
	1 ,G12,G13,G14,G15,G16,G17,G18,G19,G20	HFL0842
	REAL*8 NG	HFL0843
	COMMON /AB/A(50)	HFL0845
	COMMON /MONIT/NC14(4), CASEAV(4), NF16(6),	HFL0846
Сжжжэ	<pre> I</pre>	HFL0848
•	DATA NMAX/63/	HFL0849
Сжжжэ	DATA EPS71.D-87 {************************************	HFL0851
•	IF(PL.GT.0AND.PR.GT.0.) GO TO 7201	HFL0852
7211	FORMAT(' FROM RIEMAN, I,PL,PR=',I6,2D16.6/)	HFL0854
	CALL SOF(7654)	HFL0855
/20]	UW(6)=1,D20	HFL0857
	WL = 0.	HFL0858
	ZETAL=PL**G8	HFL0860
	ZETAR=PR**G8	HFL0861
	CRG=CRZGAMA	HFL0863
	ZSTARL=ZL	HFL0864

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HFL0865
      ZSTARR=ZR
      IF (ZETAL.LT.ZETAR) GO TO 102
                                                                                HF1 0866
  LEFT PRESSURE IS HIGHER
                                                                                HFL0867
C
      CONTINUE
 101
                                                                                HF1 0868
      EVERR=(PL-PR)/PR
                                                                                HFL0869
      USR=UR+CRG*EVERR/DSQRT(1.+G6*EVERR)
                                                                                HFL 0870
      SR=USR
                                                                                HFL0871
      UEL=UL-G7*CL*(ZETAR-ZETAL)/ZETAL
                                                                                HFL0872
                                                                                HFL0873
      SL=UEL
                                                                                HFL0874
      NL = 2
      NR=2
                                                                                HFL0875
      IF (USR.GE.UL) NL=1
                                                                                HFL0876
         (UEL.LE.UR) NR=1
                                                                                HFL0877
      TF
      IF (DABS(EVERR).LT.EPS) GO TO 100
                                                                                HFL0878
      IF (NL.EQ.2.AND.NR.EQ.1) GO TO 7001
                                                                                HFL0879
  GO TO 100
RIGHT PRESSURE IS HIGHER
                                                                                HFL0880
                                                                                HFL0881
С
 102
      CONTINUE
                                                                                HFL0882
      EVERL=(PR-PL)/PL
                                                                                HFL0883
      USL=UL-CLG*EVERL/DSQRT(1.+G6*EVERL)
                                                                                HFL0884
      SL=USL
                                                                                HFL0885
      UER=UR+G7*CR*(ZETAL-ZETAR)/ZETAR
                                                                                HFL0886
      SR=UER
                                                                                HFL0887
      NL = 2
                                                                                HFL0888
      NR=2
                                                                                HFL0889
      IF (UER.GE.UL) NL=1
                                                                                HFL0890
      IF (USL.LE.UR) NR=1
                                                                                HFL0891
      IF (DABS(EVERL).LT.EPS) GO TO 100
IF (NL.EQ.1.AND.NR.EQ.2) GO TO 7001
                                                                                HFL0892
                                                                                HFL0893
      GO TO 100
                                                                                HFL0894
 100
      CONTINUE
                                                                                HFL0895
      IF (NL.EQ.1.AND.NR.EQ.2) NCASE=1
IF (NL.EQ.2.AND.NR.EQ.2) NCASE=2
                                                                                HFL0896
                                                                                HFL0897
      IF (NL.EQ.2.AND.NR.EQ.1) NCASE=3
                                                                                HFL0898
      IF (NL.EQ.1.AND.NR.EQ.1) NCASE=4
                                                                                HFL0899
      IF(DABS(PL-PR)+DABS(UL-UR).LT.EPS*(PMAX-UMIN)) NCASE=4
                                                                                HEL0900
      UMIDA=EPS*DMAX1(CL,CR)
                                                                                HFL0901
                                                                                HFL0902
      DUDZ1 = -G7 \times C1 / ZFTA1
      DUDZR= G7*CR/ZETAR
                                                                                HFL0903
      ZETA=(-(UR-UL)+ZETAR*DUDZR-ZETAL*DUDZL)/(DUDZR-DUDZL)
                                                                                HFL0904
                                                                                HFL0905
      IF
         (ZETA.LE.0.) GO TO 7002
      \bar{N} = 0
                                                                                HFL0906
                                                                                HFL0907
      GO TO (1,2,3,4), NCASE
                                                                                HFL0908
             ES
С
   THE CASE
                                                                                HFL0909
      ITYPE=NCASE
      HELEML=.FALSE.
                                                                                HFL0910
                                                                                HFL0911
      HELEMR=.TRUE.
      N=N+1
 11
                                                                                HFL0912
      IF (N.GT.NMAX) GO TO 7003
                                                                                HFL0913
      ZETAF=ZETA
                                                                                HFL0914
      UEL=UL-G7*CL*(ZETAF-ZETAL)/ZETAL
                                                                                HFL0915
      PPR=(ZETAF/ZETAR) **NG
                                                                                HFL0916
      EVERR=PPR-1.
                                                                                HFL0917
      SQRR=DSQRT(1.+G6*EVERR)
                                                                                HFL0918
      USR=UR+CRG*EVERR/SQRR
                                                                                HFL0919
      DU=UEL-USR
                                                                                HFL0920
      IF (DABS(DU).LE.UMIDA) GO TO 10
                                                                                HFL0921
      DUDZR=NG*CRG*(PPR/ZETAF)*(1.+G9*EVERR)/SQRR**3
                                                                                HFL0922
      ZETA=ZETAF+DU/(DUDZR-DUDZL)
                                                                                HFL0923
      GO TO 11
                                                                                HFL0924
 10
      CONTINUE
                                                                                HFL0925
                                                                                HFL0926
      USTAR=(UEL+USR)/2.
      PSTAR=PPR*PR
                                                                                HFL0927
      CSTARL=CL+(UL-USTAR)/G7
                                                                                HFL0928
      RSTARL=GAMA*PSTAR/CSTARL**2
                                                                                HFL0929
      GSTARL=CSTARL*RSTARL
                                                                                HFL0930
             69.01 OF THE BOOK BY COURANT-FRIEDRICHS.
                                                                                HFL0931
C
   EQU. NO.
      WWR=G11*(USTAR-UR)*ROR
                                                                                HFL0932
      WR=WWR+DSQRT(GR**2+WWR**2)
                                                                                HFL0933
      RSTARR=ROR*WR/(WR-ROR*(USTAR-UR))
                                                                                HFL0934
      GSTARR=DSQRT(GAMA*PSTAR*RSTARR)
                                                                                HFL0935
      CSTARR=GSTARR/RSTARR
                                                                                HFL0936
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	WRE=WR/ROR+UR UW(1)=UL-CL UW(2)=USTAR-CSTARL UW(3)=USTAR	HFL0937 HFL0938 HFL0939 HFL0940
	UW(4)=WRE UW(5)=WRE G0 T0 5	HFL0941 HFL0942
С 2	THE CASE SS ITYPE=NCASE	HFL0945 HFL0944 HFL0945
21	HELEML=.TRUE. HELEMR=.TRUE.	HFL0946 HFL0947
21	IF (N.GT.NMAX) GO TO 7003 ZETAF=ZETA	HFL0948 HFL0949 HFL0950
	PF=ZETAF**NG PPL=PF/PL	HFL0951 HFL0952
	PPR=PF/PR EVERL=PPL-1.	HFL 0953 HFL 0954
	SQRL=DSQRT(1.+G6*EVERL) SQRR=DSQRT(1.+G6*EVERR)	HFL 0955 HFL 0956 HFL 0957
	USL=UL-CLGXEVERL/SQRL USR=UR+CRGXEVERR/SQRR	HFL 0958 HFL 0959
	IF (DABS(DU).LE.UMIDA) GO TO 20 DUDZI=-NGXCLGX(PPL/ZETAE)X(1.+G9XEVERL)/SQRLXX3	HFL0960 HFL0961 HFL0962
	DUDZR= NG*CRG*(PPR/ZETAF)*(1.+G9*EVERR)/SQRR**3 ZETA=ZETAF+DU/(DUDZR-DUDZL)	HFL0963 HFL0964
20	GO TO 21 CONTINUE USTAR=(USL+USR)/2	HFL0965 HFL0966
	PSTAR=(PPL*PL+PPR*PR)/2. WWR=G11*(USTAR-UR)*ROR	HFL 0968 HFL 0969
	WR=WWR+DSQRT(GR**2+WWR**2) WWL=-G11*(USTAR-UL)*ROL	HFL0970 HFL0971
	RSTARE=ROR*WR/(WR=ROR*(USTAR=UL)) RSTARE=ROR*WR/(WR=ROR*(USTAR=UR))	HFL0972 HFL0973 HFL0974
	GSTARL=DSQRT(GAMA*PSTAR*RSTARL) GSTARR=DSQRT(GAMA*PSTAR*RSTARR)	HFL0975 HFL0976
	CSTARL=GSTARL/RSTARL CSTARR=GSTARR/RSTARR	HFL0977 HFL0978
	WRE=WR/ROR+UR UW(1)=WLE	HFL0980 HFL0981
	UW(2)=WLE UW(3)=USTAR	HFL0982 HFL0983
	UW(5)=WRE GO TO 5	HFL 0984 HFL 0985 HFL 0986
С 3	THE CASE SE ITYPE=NCASE	HFL0987 HFL0988
31	HELEML=.IRUE. HELEMR=.FALSE. N=N+1	HFL 0989 HFL 0990 HFL 0991
	IF (N.GT.NMAX) GO TO 7003 ZETAF=ZETA	HFL0992 HFL0993
	UER=UR+G7*CR*(ZETAF-ZETAR)/ZETAR PPL=(ZETAF/ZETAL)**NG EVEPL=PPL-1	HFL0994 HFL0995 HFL0996
	SQRL=DSQRT(1.+G6*EVERL) USL=UL-CLG*EVERL/SQRL	HFL0997 HFL0998
	DU=USL-UER IF (DABS(DU).LE.UMIDA) GO TO 30 DUDZL=-NG¥CLG¥(PPL/ZETAE)¥() +G9¥EVERL)/S0RL¥¥3	HFL0999 HFL1000 HFL1001
	ZETA=ZETAF+DU/(DUDZR-DUDZL) GO TO 31	HFL1002 HFL1003
30	CONTINUE USTAR=(USL+UER)/2.	HFL1004 HFL1005 HFL1006
	CSTAR=CR-(UR-USTAR)/G7 RSTARR=GAMA*PSTAR/CSTARR**2	HFL1007 HFL1008

		GSTARR=CSTARR*RSTARR WWL=-G11*(USTAR-UL)*ROL WL=WWL+DSQRT(GL**2+WWL**2 WLE=-WL/ROL+UL RSTARL=ROL*WL/(WL+ROL*(US GSTARL=DSQRT(GAMA*PSTAR*F CSTARL=GSTARL/RSTARL UW(1)=WLE UW(2)=WLE UW(2)=WLE UW(3)=USTAR UW(4)=USTAR+CSTARR UW(5)=UR+CR GD T0 5	2) STAR-UL)) RSTARL)	HFL1009 HFL1010 HFL1012 HFL1013 HFL1014 HFL1015 HFL1016 HFL1017 HFL1018 HFL1019 HFL1020 HFL1021
С ₄	тні	IE CASE EE ITYPE=NCASE		HFL1022 HFL1023
		HELEML = . FALSE. HELEMR = . FALSE.		HFL1024 HFL1025
		PSTAR=ZETA**NG USTAR=UL-G7*CL*(ZETA-ZETA		HFL1026
		CSTARL=CL+(UL-USTAR)/G7 CSTARE=CR-(UR-USTAR)/G7		HFL1028
		RSTARL=GAMA*PSTAR/CSTARL	(¥2 (¥2	HFL1030
		GSTARL=RSTARL*CSTARL CSTARL=RSTARL*CSTARL		HFL1032
				HFL1034
		UW(3)=USTAR UW(3)=USTAR		HFL1035
		UW(5)=UR+CR		HFL1037 HFL1038
-		GO TO 5		HFL1039
5		DO 6 K=1,6		HFL1041 HFL1042
,		IF (UW(K).GE.0.) GO TO 61	L	HFL1043 HFL1044
6		NFLUX=6		HFL1045 HFL1046
Č 61		MIN(I)=MIN(I).OR.NCASE		HFL1047 HFL1048
C		MIN(I)=MIN(I).OR.SHIFT(N) MIN(I)=MIN(I).OR.SHIFT(N)	-LUX,9)	HFL1049 HFL1050
C		CASEAV(NCASE)=NC14(NCASE)+ CASEAV(NCASE)=CASEAV(NCASE)+	SE)+N	HFL1051 HFL1052
С		NF16(NFLUX)=NF16(NFLUX)+ IF(A(3).NE.0.)G0 TO 666		HFL1053 HFL1054
		IF(I.NE.2) GO TO 666 PRINT 667,I,NFLUX,NCASE,	PL,UL,ROL,PR,UR,ROR,USTAR,PSTAR,RSTARL,	HFL1055 HFL1056
667	, .	<pre>I RSTARR,(KK,UW() FORMAT(/1X,'I,NFLUX,NCAS)</pre>	<pre>(K),KK=1,6) E=',3I5/1X,'PL,UL,ROL,PR,UR,ROR=',6D12.4/</pre>	HFL1057 HFL1058
		1 1X, 'USTAR, PSTAR, F 2 1X, 'KK, UW(KK)=', 6	RSTARL,RSTARR=',4D13.4/ 5(I4,2X,D13.4)/)	HFL1059 HFL1060
66	6	CONTINUE RETURN		HFL1061 HFL1062
70	01	. CONTINUE PRINT 7101, PL,UL,PR,UR,2	ZETAL,ZETAR,SL,SR,NL,NR,I	HFL1063 HFL1064
71	.01	FORMAT(//1X,'FROM RIEMAN 1 //1X,'PL,UL,PR,UR	. AN IMPOSSIBLE CASE OF EXPANSION/SHOCK' =',4D25.14//	HFL1065 HFL1066
		2 1X, 'ZETAL, ZETAR 3 1X, 'NL, NR, I=', 3	,SL,SR=',4D25.14//	HFL1067 HFL1068
70	02	CALL SOF(7001) CONTINUE		HFL1069 HFL1070
71	.02	PRINT 7102, ZETA, DUDZL, DU 2 FORMAT(//1X, 'FROM RIFMAN	JDZR,ZETAL,ZETAR,PL,UL,PR,UR,N,NCASE,I NEGATIVE PRESSURE AT THE INTERSECTION'.	HFL1071 HFL1072
		1 1X, 'OF L AND R I 2 1X, 'IT MEANS TH	EXPANSION BRANCHES'// AT A CAVITATION TENDS TO FORM. THIS'.	HFL1073 HFL1074
		3 1X, 'POSSIBILITY 4 1X, 'ZETA, DUDZL, 1	IS EXCLUDED IN PRESENT VERSION'//	HFL1075 HFL1076
		5 1X, 'N, NCASE, I=', CALL SOF(7002)	3110//)	HFL1077 HFL1078
70	03	S CONTINUE PRINT 7103, I,N,NCASE,DU	,UMIDA,EPS,PL,UL,PR,UR,	HFL1079 HFL1080

<pre>1 ZETA,ZETAF,ZETAL,ZETAR,DUDZL,DUDZR</pre>	HFL1081
7103 FORMAT(//1X,'FROM RIEMAN. NUMBER OF ITERATIONS EXCEEDED.'//	HFL1082
1 1X,'I,N,NCASE,DU,UMIDA,EPS=',3I6,3D18.6//	HFL1083
2 1X,'PL,UL,PR,UR,ZETA,ZETAF=',6D18.10//	HFL1084
3 1X,'ZETAL,ZETAR,DUDZL,DUDZR=',4D18.10//)	HFL1085
CALL SOF(7003)	HFL1086
RETURN	HFL1087
END	HFL1088
SUBROUTINE MAGA(L,I,MIN) IMPLICIT REAL*8(A-H,O-Z,\$) DIMENSION MIN(L) COMMON /GAM/GAMA,NG,MU2,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11 1 ,G12,G13,G14,G15,G16,G17,G18,G19,G20 REAL*8 NG REAL*8 MU2 COMMON /STEPO/UL,PL,ROL,GL,UR,PR,ROR,GR,USTAR,PSTAR, 1 RSTARL,RSTARR,GSTARL,GSTARR,WL,WR, 2 CL,CR,CSTARL,CSTARR,UW(6) 3 ,ZL,ZR,ZSTARL,ZSTARR,NFLUX,HELEML,HELEMR LOGICAL HELEML,HELEMR COMMON /STEP1/DUIDT,DPIDT,DGIDTL,DGIDTR,DRIDTL,DRIDTR 2 ,ASTARL,ASTARR 3 ,RAT,SH COMMON /GPADS(DUDXIL DPDXIL DCDXIL DPDXIL	HFL1028 HFL1089 HFL1090 HFL1091 HFL1093 HFL1094 HFL1095 HFL1096 HFL1097 HFL1098 HFL1099 HFL100 HFL1101 HFL1101 HFL1103 HFL1103 HFL1103
<pre>1 DUDXIR, DPDXIE, DGDXIE, DGDXIE, DGDXIE, 1 DUDXIR, DPDXIR, DGDXIR, DRDXIR COMMON /AB/A(50) REAL LU, LP, LRO DATA EPS/1.D-6/ C************************************</pre>	HFL1104 HFL1105 HFL1106 HFL1107 HFL1109 HFL1110 HFL1111 EFFFL1113 HFL1114 HFL1115 EXXHFL1116 HFL1117 HFL1118 HFL1119 HFL1120 HFL1121
DU=USTAR-UL	HFL1122
Z1=1./DP	HFL1123
Z2=0.5/(PSTAR+MU2*PL)	HFL1124
ZA=Z1-Z2	HFL1125
ZB=Z1+MU2*Z2	HFL1126
LU=-ROL*DU*(GAMA*PL*ZB+0.5)+WL	HFL1127
LR0=0.5*DP/ROL	HFL1128
LP=1.+ZB*DP	HFL1130
AAL=1.+ZA*DP	HFL1131
BBL=-ZA*DU+WL/GSTARL**2	HFL1132
CCL=-LU*DUDXIL-LR0*DRDXIL-LP*DPDXIL	HFL1133
CCL=CCL-WL*USTAR*RAT/RSTARL	HFL1134
1 +UL*RAT*DU*(GAMA*PL*ZB+0.5)	HFL1135
G0 T0 10	HFL1136
12 CONTINUE	HFL1137
A1=DUDXIL+DPDXIL/GL	HFL1138
BETA=GSTARL/GL	HFL1138
ASTARL=A1+(G3/GL)*(CL*DGDXIL-G4*DPDXIL)*(BETA**G5-1.)	HFL1139
AAL=1.	HFL1140
BBL=1./GSTARL	HFL1142
CCL=-GSTARL*ASTARL/DSQRT(BETA)	HFL1143
GEOM=RAT*((GAMA-1.)*UL+2.*CL)*	HFL1144
1 (BETA**G13-1.)/(ROL*(GAMA-3.))	HFL1145
1 -4.*RAT*CL*(BETA**G14-1.)/(ROL*(3.*GAMA-5.))	HFL1146
ASTARL=ASTARL-GEOM	HFL1146
EVER1= GSTARL*GEOM/DSQRT(BETA)	HFL1147
EVER2=-RAT*USTAR*CSTARL	HFL1148
CCL=CCL+EVER1+EVER2	HFL1149
GO TO 10	HFL1150
10 CONTINUE	HFL1151
IF (.NOT.HELEMR) GO TO 22	HFL1152

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21	CONTINUE	HFL1153
	DP=PSTAR-PR	HFL1154
	DII=IISTAR-IIR	NFL1155 HEL1156
		HEL1157
	Z2=0.5/(PSTAR+MU2*PR)	HFL1158
	ZA=Z1-Z2	HFL1159
	ZB=Z1+MU2*Z2	HFL1160
	LU=~ROR*DU*(GAMA*PR*ZB+0.5)~WR	HFL1161
		HFL1162
	AAR=1.+ZAXDP	HFL1164
	BBR=-ZA*DU-WR/GSTARR**2	HFL1165
	CCR=-LU*DUDXIR-LR0*DRDXIR-LP*DPDXIR	HFL1166
	CCR=CCR+WR×USTAR×RAT/RSTARR	HFL1167
	1 +UR*KAT*DU*(GAMA*PR*ZB+0.5)	HFLI168
22		HFL1169 HEL1170
22		HFL1171
	BETA=GSTARR/GR	HFL1172
	ASTARR=A1-(G3/GR)*(CR*DGDXIR-G4*DPDXIR)*(BETA**G5-1.)	HFL1173
	AAR=1.	HFL1174
	BBR=-1./GSTARR	HFL1175
		HFLI1/6
		NFLI1//
	$2 - 4 \times RAT \times RETA \times RETA \times RETA \times REAL (ROR (3 \times RAMA - 5))$	HFI1179
	ASTARR=ASTARR+GEDM	HFL1180
	EVER1=GSTARR*GEOM/DSQRT(BETA)	HFL1181
	EVER2=RAT*USTAR*CSTARR	HFL1182
	CCR=CCR+EVER1+EVER2	HFL1183
20		HFL1184
20		HFL1105
		HFL1187
	DPIDT=-(CCL*AAR-CCR*AAL)/DET	HFL1188
	DRIDTL=DPIDT/CSTARL**2	HFL1189
	DRIDTR=DPIDT/CSTARR**2	HFL1190
	DGIDTL=0.5*GSTARL*(DPIDT/PSTAR+DRIDTL/RSTARL)	HFL1191
	DGIDIR=0.5*GSIARR*(DPIDI/PSIAR+DRIDIR/RSIARR)	HFL1192
	FND	NFL1193
	SUBROUTINE FLUXE(L,I,MIN)	HFL1195
	IMPLICIT REAL*8(A-H,O-Z,\$)	HFL1196
	DIMENSION MIN(L)	HFL1197
	COMMON /AB/A(50)	HFL1198
	\mathbb{C}	HFL1199
		HFL1200
	REAL*8 NG	HFL1202
	REAL*8 MU2	HFL1203
	COMMON /GRADS/DUDXIL,DPDXIL,DGDXIL,DRDXIL,	HFL1204
	1 DUDXIR, DPDXIR, DGDXIR, DRDXIR	HFL1205
	CUMMUN /SIEPU/UL, PL, RUL, GL, UR, PR, ROR, GR, USTAR, PSTAR,	HFL1206
	I KOTAKL, KOTAKK, GOTAKL, GOTAKK, WL, WK, 2 CL, CR, CSTAPL, CSTAPP, UW(6)	HEL1207
	3 .71.7R.7STARL.7STARR.NFLUX.HFLFML.HFLFMR	HF11209
	LOGICAL HELEML, HELEMR	HFL1210
	COMMON /STEP1/DUIDT, DPIDT, DGIDTL, DGIDTR, DRIDTL, DRIDTR	HFL1211
	2 ,ASTARL,ASTARR	HFL1212
	5 , KAI, SH	HFL1213
	COMMON ZETZETHI ETH2 ETH3 HYM DYM CYM DOWN	NFL1214
	I GIH	HEL1215
	2 ,FIH4,ZMDOTL,ZMDOTR	HFL1217
	COMMON /PRNT/ROX,PX,UX,ZX	HFL1218
C***3	***************************************	HFL1219
	ENTRY FLUXE1(L,I,MIN)	HFL1220
CXXX	**************************************	HFL1221
	DIZ-DIZZ	NFL1222
1	CONTINUE	HFL1224

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FILE: HFL
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DUDXIX=DUDXIL DRDXIX=DRDXIL DPDXIX=DPDXIL DGDXIX=0.5*GL*(DPDXIL/PL+DRDXIL/ROL) DUDTX=-DPDXIL DRODTX=-ROL**2*DUDXIL DPDTX=-GL**2*DUDXIL DRODTX=DRODTX-RAT*ROL*UL DPDTX=DRODTX*CL**2 DGDTX=G6*GL*DPDTX/PL UX = UIPX=PL ROX=ROL ZX=ZL GX=GL GO TO 9 CONTINUE 6 DUDXIX=DUDXIR DPDXIX=DPDXIR DRDXIX=DRDXIR DGDXIX=0.5*GR*(DPDXIR/PR+DRDXIR/ROR) DUDTX=-DPDXIR DPDTX=-GR**2*DUDXIR DRODTX=-ROR**2*DUDXIR DRODTX=DRODTX-RAT*ROR*UR DPDTX=DRODTX*CR**2 DGDTX=G6*GR*DPDTX/PR UX=UR PX=PR ROX=ROR ZX=ZR GX=GR GO TO 9 2 CONTINUE BETA0=(MU2*(UL/CL+G7))**(1./MU2) A1=DUDXIL+DPDXIL/GL A0=A1+(G3/GL)*(CL*DGDXIL-G4*DPDXIL)*(BETA0**G5-1.) EVER1=-((GAMA-1)*UL+2*CL)*(BETA0**G13-1.)/(GAMA-3.) EVER2=4.*CL*(BETA0**G14-1.)/(3.*GAMA-5.) EVER=(EVER1+EVER2)*RAT/ROL A0 = (A0 + EVER)DUDAX=A0 DPDAX=GL*BETA0*A0 CO=MU2*(UL+G7*CL) UX=C0 ROX=GL*BETA0/C0 ZX=ZSTARL PX=R0X*C0**2/GAMA GX=ROX*C0 DRODAX=ROL*BETA0**(1./G4) *((DRDXIL/ROL-DPDXIL/(GAMA*PL))*DSQRT(BETA0) 1 +A0/C0) 2 DGDAX=BETA0*DSQRT(BETA0)*(DGDXIL-G4*DPDXIL/CL) +G4*ROL*A0*BETA0**(1./G4) 1 DPDAX=DPDAX+RAT*UX*C0*DSQRT(BETA0) G41=1./G4+0.5 DRODAX=(DRDXIL-DPDXIL/(CL*CL)) *BETA0**G41+DPDAX/(C0*C0) DGDAX=0.5*GAMA*(PX*DRODAX+ROX*DPDAX)/GX DUDBX=-CL*BETA0**(-1./G4)/G4 DPDBX=PL*BETA0**MU2/G6 DRODBX=ROL*BETA0**(-MU2)/G4 DGDBX=GL GO TO 9 5 CONTINUE BETA0=(MU2*(-UR/CR+G7))**(1./MU2) A1=DUDXIR-DPDXIR/GR A0=A1+(G3/GR)*(-CR*DGDXIR+G4*DPDXIR)*(BETA0**G5-1.) EVER1=(-(GAMA-1.)*UR+2*CR)*(BETA0**G13-1.)/(GAMA-3.) EVER2=-4.*CR*(BETA0**G14-1.)/(3.*GAMA-5.) EVER=(EVER1+EVER2)*RAT/ROR A0=(A0+EVER)

HFL1225

HFL1226

HFL1227

HFL1228

HFL1229

HFL1230

HFL1231

HFL1232

HFL1233

HFL1234

HFL1235

HFL1236

HFL1237

HFL1238

HFL1239

HFL1240

HFL1241

HFL1242

HFL1243

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HFL1245

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HFL1249

HFL1250

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HFL1252

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HFL1272

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HFL1275

HFL1276

HFL1277

HFL1278

HFL1279

HFL1280 HFL1281

HFL1282

HFI 1283

HFL1284

HFL1285 HFL1286

HFL1287

HFL1288

HFL1289 HFL1290

HFL1291

HFL1292 HFL1293

HFL1294

HFL1295

HFL1296

DUDAX=A0

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DPDAX=-GR*BETA0*A0
                                                                            HFL1297
     C0=MU2\times(-UR+G7\times CR)
                                                                            HFL1298
     DRODAX=-ROR*BETA0**(1./G4)
                                                                            HFL1299
    1
                 *((-DRDXIR/ROR+DPDXIR/(GAMA*PR))*DSQRT(BETA0)
                                                                            HFL1300
    2
                   +A0/C0)
                                                                            HFL1301
     UX=-C0
                                                                            HFL1302
     ROX=GR*BETA0/C0
                                                                            HFL1303
     ZX=ZSTARR
                                                                            HFL1304
     PX=R0X*C0**2/GAMA
                                                                            HFL1305
     GX=ROX*C0
                                                                            HFL1306
     DGDAX=BETA0*DSQRT(BETA0)*(-DGDXIR+G4*DPDXIR/CR)
                                                                            HFL1307
                                                                            HFL1308
    1
          +G4*ROR*A0*BETA0**(1./G4)
     DGDAX=-DGDAX
                                                                            HFL1309
     DPDAX=DPDAX-RAT*UX*C0*DSQRT(BETA0)
                                                                            HFL1310
        G41=1./G4+0.5
                                                                            HFL1311
     DRODAX=(DRDXIR-DPDXIR/(CR*CR))
                                        *BETA0**G41+DPDAX/(C0*C0)
                                                                            HFL1312
     DGDAX=0.5*GAMA*(PX*DRODAX+ROX*DPDAX)/GX
                                                                            HFL1313
     DUDBX=CR*BETA0**(-1./G4)/G4
                                                                            HFL1314
     DPDBX=PR*BETA0**MU2/G6
                                                                            HFL1315
     DRODBX=ROR*BETA0**(-MU2)/G4
                                                                            HFL1316
     DGDBX=GR
                                                                            HFL1317
     GO TO 9
                                                                            HFL1318
3
     CONTINUE
                                                                            HFL1319
     UX=USTAR
                                                                            HFL1320
     PX=PSTAR
ROX=RSTARL
                                                                            HFL1321
                                                                            HFL1322
     ZX=ZSTARL
                                                                            HFL1323
                                                                            HFL1324
     GX=GSTARL
     DUDXIX=-DPIDT/GSTARL**2
                                                                            HFL1325
     DPDXIX=-DUIDT
                                                                            HFL1326
                                                                            HFL1327
     DUDXIX=DUDXIX-RAT*USTAR/RSTARL
     IF (.NOT.HELEML) GO TO 32
                                                                            HFL1328
                                                                            HFL1329
31
     CONTINUE
     DRDXIX=(RSTARL/WL)**2*(3.*DUIDT+DPIDT*(1.+3.*(WL/GSTARL)**2)/WL
                                                                            HFL1330
                                +DUDXIL*WL*((GL/WL)**2+3.)+3.*DPDXIL
                                                                            HFL1331
    1
    2
                                +DRDXIL*(WL/ROL)**2)
                                                                            HFL1332
     EVER1=UL*RSTARL**2*RAT*((GL/WL)**2+1.)/(ROL*WL)
                                                                            HFL1333
     EVER2=2.*RSTARL*USTAR*RAT/WL
                                                                            HFL1334
                                                                            HFL1335
     DRDXIX=DRDXIX+EVER1+EVER2
     GO TO 33
                                                                            HFL1336
                                                                            HFL1337
32
     CONTINUE
     BETA=GSTARL/GL
                                                                            HFL1338
     SQB=DSQRT(BETA)
                                                                            HFL1339
     DRODA=ROL*BETA**(1./G4)*(SQB*(DRDXIL/ROL-DPDXIL/(GAMA*PL))
                                                                            HFL1340
                                                                            HFL1341
    1
                                +ASTARL/CSTARL)
     DRDXIX=DRODA/SQB+DPIDT/(GSTARL*CSTARL**2)
                                                                            HFL1342
     DPDA=GSTARL*(ASTARL+RAT*USTAR*CSTARL/(GL*
                                                    SQB))
                                                                            HFL1343
     G41=1./G4+0.5
                                                                            HFL1344
     DRODA=(DRDXIL-DPDXIL/(CL*CL))
                                       *BETA**G41+DPDA/(CSTARL**2)
                                                                            HFL1345
                DRODA/SQB+DPIDT/(GSTARL*CSTARL**2)
                                                                            HFL1346
     DRDXIX=
33
     CONTINUE
                                                                            HFL1347
     DGDXIX=0.5*GX*(DPDXIX/PX+DRDXIX/ROX)
                                                                            HFL1348
     DUDTX=DUIDT
                                                                            HFL1349
                                                                            HFL1350
     DPDTX=DPIDT
     DGDTX=G6*GSTARL*DPIDT/PSTAR
                                                                            HFL1351
     DRODTX=DPIDT/CSTARL**2
                                                                            HFL1352
     GO TO 9
                                                                            HFL1353
                                                                            HFL1354
4
     CONTINUE
     UX=USTAR
                                                                            HFL1355
     PX=PSTAR
                                                                            HFL1356
     ROX=RSTARR
                                                                            HFL1357
                                                                            HFL1358
     ZX=ZSTARR
     GX=GSTARR
                                                                            HFL1359
                                                                            HFL1360
     DUDXIX=-DPIDT/GSTARR**2
     DUDXIX=DUDXIX-RAT*USTAR/RSTARR
                                                                            HFL1361
                                                                            HFL1362
     DPDXIX=-DUIDT
     IF (.NOT.HELEMR) GO TO 42
                                                                            HFL1363
41
     CONTINUE
                                                                            HFL1364
     DRDXIX=(RSTARR/WR)**2*(3.*DUIDT-DPIDT*(1.+3.*(WR/GSTARR)**2)/WR
                                                                            HFL1365
    1
                                -DUDXIR*WR*((GR/WR)**2+3.)+3.*DPDXIR
                                                                            HFL1366
    2
                                +DRDXIR*(WR/ROR)**2)
                                                                            HFL1367
     EVER1=UR*RSTARR**2*RAT*((GR/WR)**2+1.)/(ROR*WR)
                                                                            HFL1368
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	EVER2=2.*RSTARR*USTAR*RAT/WR DRDXIX=DRDXIX-EVER1-EVER2	HFL	1369 1370
62	GO TO 43 CONTINUE	HFL	1371
42	BETA=GSTARR/GR	HFL	1372
	SQB=DSQRT(BETA) DPODA==POPERETAXX(1, /C()X(SORX(=DPDYTP/POP+DPDYTP/(CAMAXOP))	HFL	1374
1	+ASTARR/CSCTARR)	HFL	1375
	DPDA=-GSTARR*(ASTARR+RAT*USTAR*CSTARR*(GR* SQB))	HFL	1377
	DRODA=(DRDXIR-DPDXIR/(CR*CR)) *BETA**G41+DPDA/(CSTARR**2)	HFL HFL	1379
63	DRDXIX= DRODA/SQB-DPIDT/(GSTARR*CSTARR**2)	HFL	1381
75	DGDXIX=0.5*GX*(DPDXIX/PX+DRDXIX/ROX)	HFL	1383
	DUDIX=DUIDT DPDTX=DPIDT	HFL HFI	1384 1385
	DGDTX=G6*GSTARR*DPIDT/PSTAR	HFL	1386
	GO TO 9	HFL	1387
9		HFL	1389
C****	****	HFL	1391
. *****	ENTRY FLUXE2(L,I,MIN) ************************************	HFL HFI	1392 1393
•	FI1=ROX*UX	HFL	1394
	FI2=RUX*UX**2+PX FI2=FI2-PX	HFL HFL	1395
	FI3=UX*(G12*PX+0.5*R0X*UX**2+ZX*R0X*QDET)	HFL	1397
	R0U00=R0X*UX	HFL	1399
1.0	GO TO(10,20,30,40,50,60), NFLUX	HFL	1400
60	CONTINUE	HFL	1402
	DFDXII=DKDXIX*UX+RUX*DUDXIX DFDXI2=DRDXIX*UX**2+2.*ROX*UX*DUDXIX+DPDXIX	HFL HFL	1403
	DFDXI2=DFDXI2-DPDXIX	HFL	1405
1	+UX*(G12*DPDXIX+0.5*DRDXIX*UX*X2+ROX*UX*DUDXIX)	HFL	1407
	DFIDT1=DRODTX*UX+ROX*DUDTX DFIDT2=DRODTX*UX*X2+2 *ROX*UX*DUDTX+DPDTX	HFL HFI	$1408 \\ 1409$
	DFIDT2=DFIDT2-DPDTX	HFL	1410
1	DFIDF3=DUDFX*(G12*PX+0.5*RUX*UX**2) +UX*(G12*DPDTX+0.5*DR0DTX*UX**2+R0X*UX*DUDTX)	HFL HFL	1411
_	FIDOT1 = -ROUGO * DFDX11+DFIDT1	HFL	1413
	FIDOT3=-ROUOO*DFDXI3+DFIDT3	HFL	1415
	UXDOT=-ROUCO*DUDXIX+DUDTX PYDOT=-ROUCO*DUDXIX+DUDTX	HFL HFI	1416
	GXDOT=-ROUOO*DGDXIX+DGDTX	HFL	1418
	ROXDOT=-ROUOO*DRDX1X+DRODIX FIH1=FI1+DT2*FIDOT1	HFL HFL	1419
	FIH2=FI2+DT2*FID0T2	HFL	1421
	FIH3=FI3+DT2*FIDOT3	HFL	1423
	FIH4=FI4	HFL HFL	$1424 \\ 1425$
	PXN=PX+DT*PXDOT	HFL	1426
	GXN=GX+DT*GXD01 R0XN=R0X+DT*R0XD0T	HFL	1427
20	GO TO 90	HFL	1429
20	EV0=GL*DSQRT(BETA0)	HFL	1431
201	CONTINUE DEIDAI=DRODAX¥UX+ROX¥DUDAX	HEL	1432
	DFIDA2=DRODAX*UX*X2+2.*ROX*UX*DUDAX+DPDAX	HEL	1434
	DFIDA2=DFIDA2-DPDAX DFIDA3=DUDAX*(G12*PX+0.5*R0X*UX**2)	HFL	1435
1	+UX*(G12*DPDAX+0.5*DRODAX*UX**2+ROX*UX*DUDAX)	HEL	1437
	FIDOT2=-EVO*DFIDA1 FIDOT2=-EVO*DFIDA2	HFL	1439
	FIDOT3=-EV0*DFIDA3	HFL	1440

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	FIH1=FI1+DT2*FIDOT1 FIH2=FI2+DT2*FIDOT2 FIH3=FI3+DT2*FIDOT3 FIH4=FI4
	IF(NFLUX.EQ.5)GA=-GA DROUA=UX*DRODAX+ROX*DUDAX
	BETAPR=0.5*DSQRT(BETA0)*(GA-DROUA) FIH2=FIH2-DPDBX*BETAPR*DT2
	$UXDOT = -EVO \times DUDAX + BETAPR \times DUDBX$ PXDOT = -EVO \times DPDAX + BETAPR \times DPDBX
	GIH=PX+DT2*PXDOT GYDOT=-EVA*DGDAY+BETAPR*DGDBY
	ROXDOT = - EVO*DRODAX+BETAPR*DRODBX
	PXN=PX+DT*PXDOT
	ROXN=ROX+DT*ROXDOT
50	CONTINUE
	EV0=-GR*DSQRT(BETA0) G0 T0 201
30 40	CONTINUE
9.0	
	RETURN END

HEL1661
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